Unesco-UNEP International Environmental Education Programme

Environmental Education Series 11

ENERGY: AN INTERDISCIPLINARY THEME FOR ENVIRONMENTAL EDUCATION

Division of Science, Technical and environmental Education

Unesco-UNEP
International Environmental Education Programme

Environmental Education Series **11**

Energy: an interdisciplinary theme for environmental education

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UNESCO

Division of Science, Technical
and Environmental Education

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PREFACE

International and regional meetings held since 1975 as part of the Unesco-UNEP International Environmental Education Programme (IEEP) and particularly the International Conference on Environmental Education held in Tbilisi, Union of Soviet Socialist Republics, in 1977, have stressed the importance of providing those involved at various levels of the educational establishment with guidelines and conceptual instruments likely to stimulate the development of environmental education.

To that end, the IEEP has initiated national research and pilot projects and training seminars in more than 60 Member States in various parts of the world aimed at fostering the development of topics, methods and materials for that type of education. The resulting experience has gone into the preparation of a series of experimentally oriented publication for the purpose of dealing with current environmental problems by an interdisciplinary educational approach which meets the methodological demands of the various levels and types of school education and the training of teachers.

The scope and diversity of modern environmental problems are such that many spheres of life lend themselves to environmental education (EE); these include the utilization and management of natural resources, nutrition and health, the environmental problems of urban areas, the control and alleviation of various forms of pollution, etc.

'Energy: an interdisciplinary topic for environmental education' is not an exhaustive discussion of all environmental questions; rather does it try to give an original presentation of certain select topics connected with energy, while stressing the complex and comprehensive nature of the problems involved. Moreover, it uses an educational approach based on an active and interdisciplinary treatment of environmental education within the frame of general school education.

Teachers and students in secondary schools for whom this work is primarily intended, but other readers as well, should remember the experimental nature of the contents, methods and examples used and hence to view them critically before applying them in practice.

This publication has been prepared as part of the Unesco-UNEP international environmental education programme by a team of specialist members of EDEN(1) (Ecologie, Développement et Energétique) directed by Mrs Jean-Paul Deleage and Christian Souchon, both of the University of Paris VII.

Finally, IEEP would like to thank the Information Department of Electricité de France for allowing them to use their pamphlet '26 Leçons sur l'Energie' (26 lessons on energy), the text of which, slightly amended and amplified, has been used in the second part of this text.

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(1) EDEN: 18 rue des Fosses-St.-Jacques, 75005 Paris, France.

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CONTENTS

	Page
INTRODUCTION	1
PART ONE: ENERGY IN THE UNIVERSE AND IN HUMAN SOCIETY	3
Chapter I: Energy in the cosmos and in the biosphere	5
Chapter II: Evolution of societies and energy use	11
Chapter III: Energy sources and resources	15
Chapter IV: Use and management of energy resources	23
PART TWO: ENERGY AS A THEME OF ENVIRONMENTAL EDUCATION	41
Chapter I: The educational methods and their application	43
Chapter II: Description of the module and of its uses	57
Chapter III: Energy-theme module	65
Section I: Energy: definititions and forms . .	67
Section II: Units of energy and power: efficiency	70
Section III: History of the utilization of energy	75
Section IV: Energy chains and the transport of energy	80
Section V: Energy sources and resources . . .	85
Section VI: The production of energy	100
Section VII: The consumption of energy	108
Section VIII: The economics of energy and energy savings	121
Appendix I: Additional comments on some basic concepts	125
Appendix II: Data for drawing up energy balances	151
Appendix III: Glossary of some terms related to energy	159
Appendix IV: Bibliography	165

INTRODUCTION

Energy problems are becoming increasingly important in the general context of the control of resources: they involve the amounts of energy available, the cost of obtaining them, the political and economic constraints, the exhaustion of reserves ... While these problems sometimes impinge on certain economic features of the industrialized countries, they are also of crucial importance to the developing countries: in fact, if these countries are to have a harmonious future, they must have some access to energy resources and learn to husband them by the most careful decisions based on the best possible situation analysis and on maximum practical knowledge.

Side by side with technical efforts or attempts to optimize economic exchanges, a broad educational campaign can foster more appropriate attitudes to the husbanding of energy resources, on the individual level no less than within larger or smaller social communities.

In fact, the consumer considered as a responsible social agent on the one hand, and the general economic system on the other hand, far too often appear as separate entities, when the sum total of direct or indirect individual consumption of energy has a marked effect on the overall exploitation of resources. Knowledge of all the implications of the use of energy resources is a prerequisite of the training of individuals familiar with environmental problems and with their causes. Energy is one of the most fundamental topics in this area: in fact, no human activity can be performed without raw materials, without human labour ... and without energy.

However, because of the larger number of concepts involved, it is difficult to make the subject of energy the direct basis of environmental education. In fact, that subject demands the greatest possible number of contributions from various disciplines. This fact encourages the use of an interdisciplinary approach which is indeed considered one of the essential characteristics of environmental education: energy looms large among the so-called integrating or federating themes.

One of the first requirements of an interdisciplinary approach (as distinct from a pluridisciplinary approach which is confined to a mere juxtaposition of disciplines) is that teachers who have specialized in one disciplinary field should have access to the concepts of other disciplines. This seems a prerequisite on the one hand of serious communication between members of the teaching team, and on the other hand of a systematic approach clearly demonstrating the global character of a given theme and the links between the theoretical concepts and the socio-economic situation (including environmental problems).

Now, the creation of interdisciplinary cohesion in teaching teams based on a sound initial understanding of the concepts involved, was the main reason for preparing this publication. To that end we have tried:

to present in simple form all the conceptual elements needed to grasp the special characteristics of energy and the practical consequences inherent in its use;

to define the links between energy and society with the help of data bearing on the problems of the supply, production, use and consumption of energy;

to introduce, into the educational field, such methodological considerations and modular elements as will render possible the performance of concrete tasks, justified and supported by adequate prior reflection.

This paper consists of two main parts and several appendixes. The first, more complex, part is chiefly addressed to teachers: it is a reflection on, and an analysis of, problems connected with the control of energy in the contemporary world. The second part is more concerned with practical teaching methods: while its first section examines methods most appropriate to environmental education and to the theme under discussion; the second and third sections are intended to provide, in the form of an educational module, a didactic method for direct use with and by pupils. This module comprises: (a) texts presenting energy concepts in a simplified way and laying the foundations for discussions leading to educational activities; (b) worksheets for use with, or after reading of, the suggested texts.

The first of the appendixes is meant for readers hoping to gain a deeper knowledge of concepts used in discussions of energy; the remainder presents a new methodological approach to energy control, namely eco-energy balance-sheets, and a glossary.

Though this paper is chiefly addressed to the educational sector, it may also prove useful to energy users faced with concrete problems of energy consumption and control in the course of agricultural activities, running a small industry, building, home life ... All these areas pose special problems that do not seem to have been fully resolved to date (public awareness, methods, special education ...).

It must, finally, be underlined that this module has an experimental character. Readers in general and teachers in particular are accordingly invited to approach the contents, the methods and the examples with a critical eye, to adapt them to local conditions and to evaluate their educational effectiveness accordingly.

PART ONE

ENERGY IN THE UNIVERSE AND IN HUMAN SOCIETY

CHAPTER I: ENERGY IN THE COSMOS AND IN THE BIOSPHERE

I. ENERGY IN THE COSMOS

Over the centuries, the known frontiers of our universe have been receding. Galileo realized that the Milky Way was 'a cluster of luminous stars', and we know today that the cosmos is made up of innumerable stars combined into innumerable galaxies.

Galaxies are collections of stars; their structure and dimensions are highly variable. The smallest galaxies contain thousands of millions of stars; giant galaxies contain hundreds of thousands of millions. Bright as 10,000 million suns, the big galaxies still visible to us are thousands of millions of light years away - one light year is the distance travelled by light in one year - and the speed of light is 300,000 km per second! Our galaxy, the Milky Way, with its thousands of millions of stars is a medium-sized galaxy. It is the shape of an immense disc with a diameter of 100,000 (10^5) light years!

The sun is just one star among many, albeit the most important for us. In 1963, two astrophysicists (Schmidt and Sandage) discovered stellar objects of a different type. These objects emitted radio waves and they called them quasars (or quasi-stellar sources). Quasars are situated at the confines of our Universe now being explored by radio astromoners and are a hundred times more powerful than the greatest of galaxies. A single quasar is the centre of physical processes capable of releasing a flux of energy a billion (10^{12}) times that generated by the sun.

It was not until the twentieth century that the methods of producing and transferring the enormous quantities of energy found in stellar objects began to be explained; before that could happen the physical nature and structure of stars had first to be elucidated on the macroscopic scale, together with the mechanisms of nuclear reactions leading to the transformation of matter into energy on the microscopic scale. The stars radiate energy: they are the centre of irreversible energy-releasing structural changes.

However, these changes are generally too slow to make themselves felt on the scale of human history. Physicists have shown that the nuclear reactions triggered off by high stellar temperatures are the main source of energy in the stars. However, at certain phases of stellar development, other forms of energy also play an important role: gravitational energy in the case of stars in the process of formation, thermal energy in white stars, etc.

Let us now give a highly simplified account of how astrophysicists view the development of most stars. Initially, a cloud of interstellar gas is subjected to two types of force: (a) the force of gravity which tends to compress the particles, the outer layers pressing on the inner layers; and (b) the random thermal agitation of the particles which, by contrast, tends to disperse the cloud. Under certain conditions of temperature, density, etc., which can be determined by physicists, the gravitational forces prevail over the dispersive forces and we then witness the contraction of the cloud under the effect of the gravitational forces. There has been a transformation of the potential energy of gravity into the internal energy of the embryonic star, whose temperature and density keep increasing. When these two parameters reach high enough values (the temperature measuring millions of degrees), thermonulcear reactions are triggered off in the central regions. The transformation of matter into energy releases the radiation responsible for the luminosity of

the star. In the course of time, the chemical composition of the star begins to change, with consequent changes in structure and luminosity and a loss of mass: a 'hot' star is transformed into a 'cold' star.

In 1938, Hans Bethe put forward a theory to explain nuclear transformations in the interior of the sun and similar stars. The extreme temperatures in the interior of the sun together with the fantastic pressure exerted by its mass cause the fusion of hydrogen nuclei. The fusion of our hydrogen nuclei leads to the formation of a helium nucleus whose mass is slightly smaller than that of the four initial particles. All in all, every single second, 582 million tons of hydrogen in the sun are transformed into 578 million tons of helium. The difference in mass is transformed into radiant energy. As a result, 625 billion joules of energy are released for every gram of helium formed. The power thus generated by the sun is put at $3.73\ 10^{23}$ kW, or $8.91\ 10^{15}$ tonnes of oil equivalent per second; knowing the mass of the sun we can determine the approximate time when its reserves of energy will be exhausted (if it continues to shine with the same brightness); the answer is 7,000 million years. The figures we have just presented are intended to convey a rough idea of the scope and complexity of the energy processes at work in the cosmos. The orders of magnitude to which we are accustomed here on earth do not suffice to evaluate and analyse them: indeed, all our classical concepts of time and space are inadequate. Moreover, physicists do not always agree on the correct interpretation of the phenomena they observe nor on the history of the universe they can reconstruct from their observations. For our part, we need merely recall that, quite generally, matter and energy are the two forms in which the universe is revealed to us: increases and decreases in energy invariably go hand in hand with decreases or increases in mass. One of the major scientific and technical problems of our times is the management, for the good of mankind, of just one tiny bit of cosmic energy, namely that bit which reaches us from our own small star: the Sun.

Mankind, in fact, has no energy sources other than:

'the heat of the sun' and its present-day by-products (biomass, wind, hydraulic energy ...) or its fossilized by-products (petroleum, gas, coal ...);

'the heat of the earth' in active (geothermal) form or awaiting release (nuclear fuels);

interstellar attraction (gravitational energy) expressed concretely in the movement of the tides.

II. ENERGY IN THE BIOSPHERE: ECOSYSTEMS

1. General

The problem of the utilization of energy by human societies cannot be grasped without some knowledge of the elementary principles governing man's place in the biosphere as a biological species: the plants and animals on which he feeds, the forests he exploits for his heating and for cooking his food, are all part of a living world subject to ecological laws.

Moreover, however artificial our own lives may have become, we ourselves are placed at the peak of ecological pyramids which, starting from the sun, lead up to man through plants and animals. Ecology, the study of the relationship between living organisms and their environment, helps us to a better

appreciation of the place of energy in our life. Now, to study the role of energy in the living world, we are forced to divide that world into ecosystems, so many 'pieces of nature' (a prairie with the herds of herbivorous animals who feed on it and the micro-organisms that recycle the waste products; a forest with all the plant and vegetable species that constitute it and live in it both on the surface and in the soil).

2. The structure of ecosystems

We can treat ecosystems as complex thermodynamic systems open to the environment. Open to the environment because, in order to function they need energy and materials they can assimilate; complex because they are made up of parts that perform different functions: while some organisms (green plants) can capture solar energy directly, others can only use the energy of other organic matter. The first group, the green plants, called primary producers, are able to synthesize their own organic substance with the help of solar energy. This synthetic process is completed with the help of carbon dioxide, water and solar energy.

Plants that can capture solar energy and use it directly are called autotrophic (a synonym for carbon-users since they form their organic substance directly from the carbon present in atmospheric carbon dioxide or, in the case of aquatic plants, from carbon ions in the water).

A second group is made up of animals feeding on plants (phytophagous animals). They are secondary converters: incapable of using solar energy directly, they depend on the energy accumulated in plants or in other animals; they are said to be heterotrophic (i.e. their food is based on organic molecules elaborated by other living organisms).

Some heterotrophic organisms feed directly on plants: the big herbivores, insects, etc. Next come the carnivores, animals that eat animal flesh, i.e. feed on herbivores. Some organisms, including man, can feed on both plants and animals.

We can now paint the following picture of the ecosphere: all life comes from the sun; sunlight is captured by plants which transform it by photosynthesis into the organic matter constituting the vegetation of forests, prairies, fields, marine plankton, etc. That vegetation is eaten by animals and by man. A third category of (heterotrophic) organisms uses waste, dead matter, and cadavers: it is part of complex chains of detritivores. The smallest of these organisms are the so-called bioreducers (bacteria and fungi) which cause the disappearance of organic matter and release its constituents into the environment (hence they are also referred to as mineralizers).

At every level, organisms live and develop by drawing what energy they need for their own metabolic maintenance or for growth, from the previous level. Every organism absorbs a great deal of energy to store a relatively small amount of energy in the bonds of its molecules; as a result the metabolism of every organism involves the surrender to the environment of a great deal of degraded energy produced by respiratory processes. Hence in an ecosystem in equilibrium, i.e. of constant mass, the respiratory activity of all the organisms ensures that the whole of the energy originally fixed by photosynthesis is dissipated: we say that a flow of energy traverses the ecosystem.

Every category of the organisms making up the ecosystem constitutes a trophic level: the various trophic levels are organized into a trophic or alimentary chain which, in its turn, reflects the energy relationships between

these levels (when we try to represent relationships between species, we obtain a more complicated picture, namely a trophic network).

3. The energy efficiency of ecosystems

(a) Biomass and productivity

For every trophic level we can determine a biomass: the mass of living organisms expressed either in mass of dry matter or as the energy equivalent per unit surface (e.g. tonnes/hectare, kilocalories/m^2 ...). For terrestrial ecosystems the most important biomass is that corresponding to the vegetation, i.e. to the level of primary producers; it is the smaller the higher we go up the ladder: this fact can be represented graphically by a so-called biomass pyramid.

Biological productivity is the quantity of living matter elaborated in a given period by a given biomass. It is helpful to express this quantity by its energy equivalent. Biomass and productivity have been rightly compared to capital and interest. Productivity is often expressed in terms of an annual production cycle (e.g. kcal/ha/year). Like the biomass, it can be represented graphically by a (productivity) pyramid.

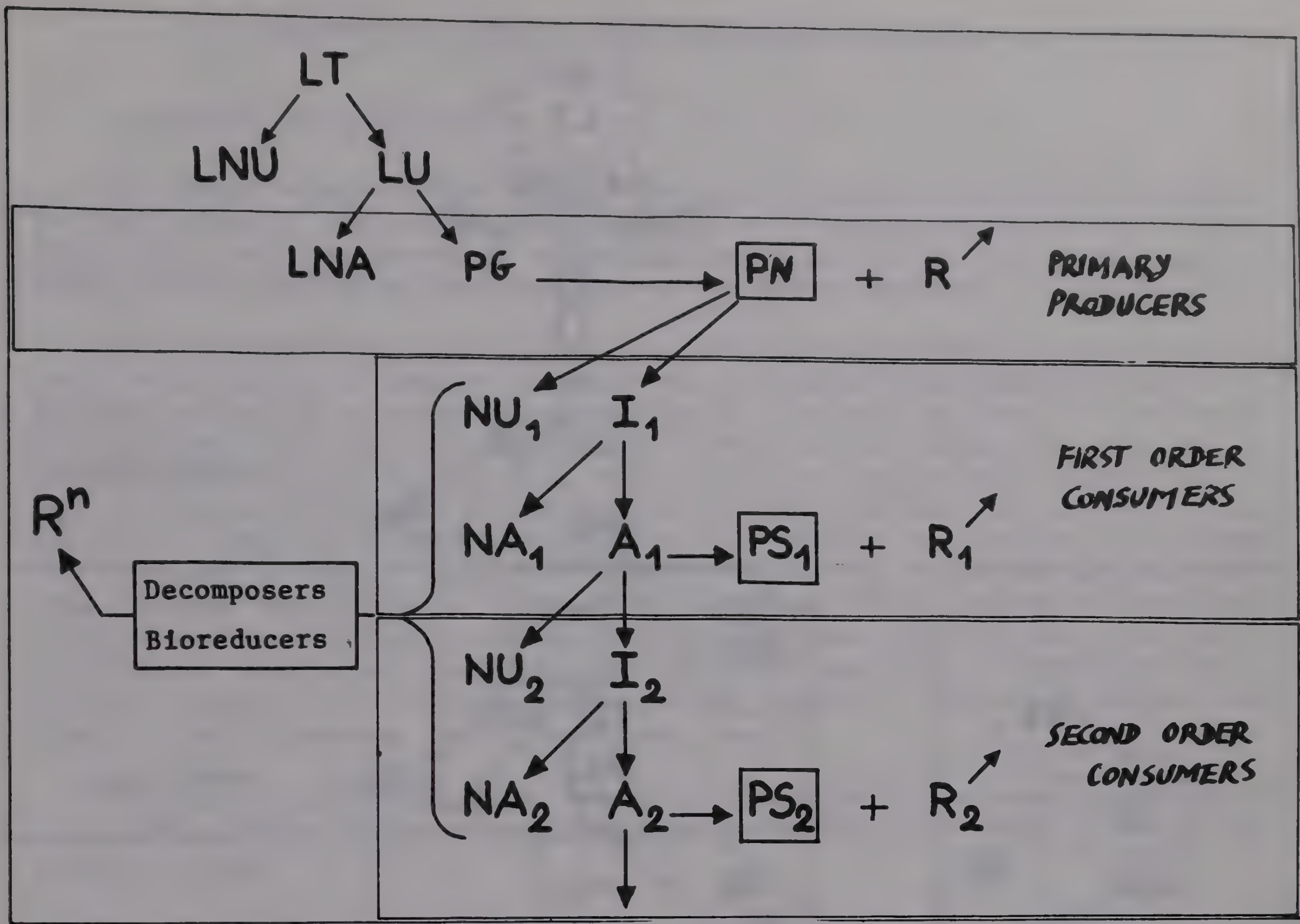
(b) Energy flow in ecosystems

An ecosystem cannot function unless it is traversed by a constant flow of energy. The incoming part of this flow corresponds to the solar energy used, and the outgoing part to the energy spent on respiratory exchanges by all the organisms constituting the ecosystem.

The following diagram illustrates the structure of this flow within the ecosystem divided into trophic levels.

(c) Efficiency of ecological chains and the productivity/biomass ratio

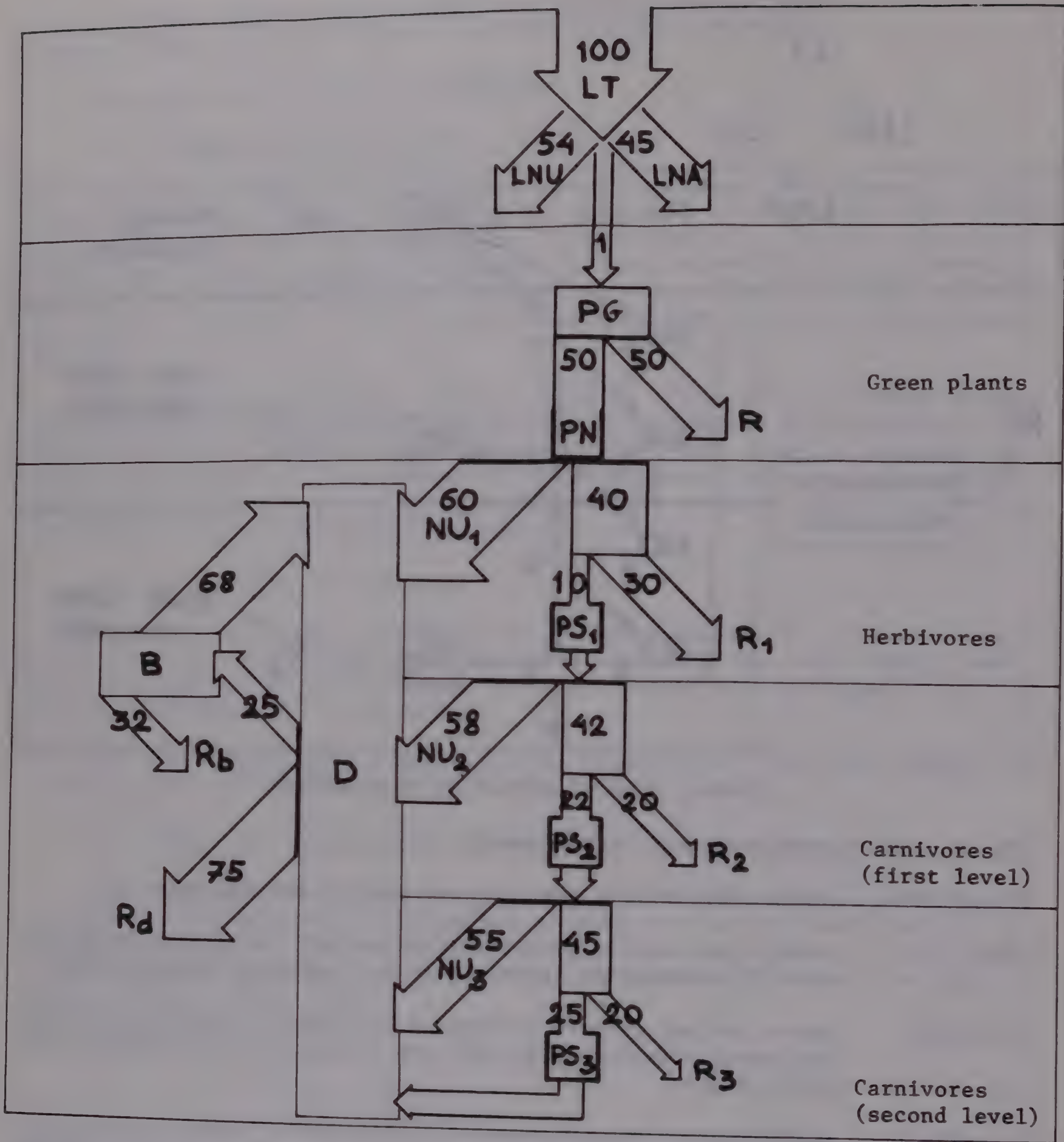
The quantity of energy which, starting from solar energy, goes into the formation of organic matter represents no more than a very small portion of the total energy available; the ratio (PG/LT) is of the order of 1 per cent. Then, as we pass from one trophic level to the next, we find that the ratio is of the order of 10 per cent.



GENERAL FLOW OF ENERGY IN AN ECOSYSTEM

LT:	total radiant (light) energy
LU and LNU:	parts respectively used and not used by the ecosystem
LNA:	energy not used by plants for chlorophyll assimilation; in the case of terrestrial plants, this part supports transpiration
PG and PN:	gross and net primary production by primary converters, R being the energy dissipated in the form of heat by the respiration of green plants
I_1 and I_2:	quantities of energy ingested in the form of food by consumers of the first order (herbivores) and by consumers of the second order (carnivores)
NA_1 and NA_2:	non-assimilated fractions; NU_1 and NU_2: fractions of these trophic levels not used by the next level
PS_1:	net production of herbivores whose A_1 (assimilated energy) roughly represents the gross production

The organic matter corresponding to the quantities NU_1, NA_1, NU_2, NA_2, enter into a subsidiary chain: that of the decomposers and bioreducers whose respiration is expressed by R_n.



ENERGY FLOW THROUGH A DECIDUOUS FOREST IN A TEMPERATE REGION (after MacCormick, 1959, partly modified). The figures are expressed in successive percentages of LT, PG, PN, PS_1, PS_2, D (productivity of decomposers) and B (productivity of bioreducers). R_d and R_b give the energy spent by decomposers and bioreducers respectively.

CHAPTER II: EVOLUTION OF SOCIETIES AND ENERGY USE

I. HISTORICAL INTRODUCTION

Two great stages in the history of mankind mark the use of solar energy: the emergence of agriculture during what has become known as the neolithic revolution, and the advent of industrial societies at the end of the eighteenth century following the invention of the steam engine.

In a predominantly agricultural society of the neolithic type, the sun is man's sole source of energy and that energy reaches him almost exclusively through ecological systems; to the energy of food must be added the energy of fire derived from wood and possibly the energy due to animal traction. All in all, each individual in that type of society can draw on about 10,000 kcal a day. At the opposite end, in contemporary industrialized civilizations, there has been a complete change in the energy flow used by man, thanks to his massive recourse to fossil fuels: solar energy stored by ecosystems in geological time. In the United States of America, nowadays, every individual can draw 250,000 kcal a day. Hence, whereas in a traditional society, man drew just a fraction of the solar energy trapped in ecosystems, in an industrialized society, social life involves a large-scale tapping of the energy capital laid down in fossil reserves (coal, petroleum, gas).

The way in which the use of energy is organized in human societies can be described with the help of such simple concepts as converters, channels and energy systems.

II. CONCEPTS CONNECTED WITH THE USE OF ENERGY IN HUMAN SOCIETIES

In all societies, men face the problem of the transformation of an enormous flux of crude energy that reaches our planet in potentially usable form: we need only recall that solar energy alone represents 10,000 times the sum of all the energy used by contemporary societies. Converters have the job of transforming this crude energy into useful energy. We distinguish between <u>biological converters</u> such as plants and animals, and <u>artificial converters</u> such as water wheels and steam engines. Converters differ in both the type of energy they work on and also in <u>efficiency</u>. Efficiency is defined as the ratio of the useful energy supplied by the converter to the energy it consumes. Thus the efficiency of a steam engine or of an internal combustion engine is defined as the ratio of the mechanical energy made available through the drive shaft to the energy contained in the fuel used (coal, petrol, etc.).

Man himself is a converter. He absorbs energy in the form of food (about 3,000 kcal a day) produced with the help of solar energy by plants and animals. Half that energy, or about 1,500 kcal represents man's basic metabolic needs; the remaining 1,500 kcal can be transformed into mechanical energy with an efficiency of about 20 per cent. Hence man can invest about 300 kcal of useful mechanical energy a day in various social activities. For centuries, the human converter has been the most closely studied, not least because its 'efficiency' is the highest in the animal kingdom. The 'efficiency' of a horse hardly exceeds 10 per cent, and that of an ox is lower still. In past centuries when tools or machines were rather imperfect and the methods of animal traction rather ineffective, slavery, however abhorrent, must have seemed a highly rational system of energy conversion.

The use of new machinery, such as water wheels, better harness, the choice of more productive vegetable converters have given man control over additional amounts of energy in increasingly varied forms. In practice, the conversion of raw energy (solar energy, coal seams, etc.) into usable energy (heat, motion ...) calls for not just one converter but a whole chain of converters corresponding to the different phases of utilizing the initial resource (extraction or collection, transport, etc.). The efficiency of a chain of converters is defined as the product of the efficiency of the successive converters of which it is made up.

In general, a chain of converters must, according to J. Lacoste(1) satisfy three compatibility rules, or constraints:

- Quantitative constraints: It is impossible to use just any form of energy for just any purpose. In other words, the final energy must satisfy precise demands: nourishment, heating, mechanical work, etc., and hence must present itself in specific forms: food, wood, steam, petrol, electricity ... Without certain converters it is impossible to use various natural resources efficiently: without a steam engine the thermal energy liberated by the combustion of coal cannot be converted into mechanical energy; before the use of sails or windmills, wind energy could not be converted into mechanical energy, etc.

- Locational constraints: A human community needs energy at home or at work. Here we have a fundamental problem: the difficulties of transporting energy (wood, for example) have for millennia been so many obstacles to human progress. In that respect, one of the major features of the industrial revolution has been the spectacular drop in the energy cost of overland transport. Compatibility of place has been achieved in various ways in the course of history: the development of large-scale transport systems, for instance for the transport of wood in the Muslin Mediterranean(2) from Western Europe to the Middle East between the seventh and tenth centuries, and for the transport of petrol from the Middle East to Western Europe in the twentieth century.

- Time constraints: Continuous food supplies must be ensured though harvests are concentrated in short periods during the year; there is an increased demand for fuel during the winter in cold countries, etc. Providing for this compatibility means deploying storage and distribution systems which use up energy: generally, this time constraint calls for extra storage and distribution to meet peak demand or certain (e.g. climatic) hazards. This factor must obviously be borne in mind when computing the overall efficiency of energy chains.

Most discussions of the role of energy in our society reflect partial points of view. A more general approach must be based on the idea of energy systems, which also includes the social structures needed for the exploitation and control of energy sources and converters: that approach helps to account for the development of, and changes and substitutions in, the various energy chains recorded in history.

(1) J. Lacoste et al. 1982, L'énergie c'est quoi?, Vol. I, pp. 1-70, Electricité de France, Paris.
(2) Cf. M. Lombard: 'Arsenaux et bois de marine dans la Méditerranée Musulmane, VII-XIème siècles' in Espaces et Réseaux du Haut Moyen Age, Mouton, Paris (1972), pp. 140 ff.

An energy system is the original combination of various energy chains. It can be defined on different scales: by region, by country or by group of countries. But the concept can also be applied to an industrial complex, to a form, to a village, etc. ...; some chains constituting systems have moreover existed throughout human history. A case in point is the human energy chain, albeit the status of human labour in the slave societies of antiquity obviously differed from that in West European feudal societies or under modern capitalism. If we take other examples, for instance coal, the first fossil resource man exploited on a massive scale, or oil, the main contemporary source of energy, we know that these substances, too, were known in antiquity: Herodotus remarked on the luminous properties of petroleum in Babylon. Coal had replaced wood long before the industrial revolution in Britain for certain domestic applications. However, the use of coal was not organized seriously until the advent of the steam engine and related machinery.

The first elements for defining an energy system are therefore its geological, geographical, technical, ... characteristics, namely the location of the source the gross energy; systems of collection or extraction; transport and storage; converters and final energy.

Another set of elements for defining energy systems is based on the forms of appropriation governing the organization of converters and the modes of energy consumption.

III. LINKS BETWEEN ENERGY AND TYPES OF CIVILIZATION

Let us return to the case of the human converter. During the third millennium BC a profound change occurred in its utilization: if we look at the earliest civilizations in Sumer and Egypt, we find that their main source of energy was agriculture as it had been in the neolithic societies from which these civilizations had sprung. However, these kingdoms not only ushered in a host of technical improvements but also harnessed 'the power of a new kind of organization', as Lewis Mumford has called it:

> 'Men of ordinary capacity, relying on muscle power and traditional skills alone, were capable of performing a wide variety of tasks, including pottery manufacture and weaving, without any external direction or scientific guidance, beyond that available in the tradition of the local community. Not so with the megamachine. Only kings, aided by the discipline of astronomical science and supported by the sanctions of religion, had the capability of assembling and directing the megamachine. This was an invisible structure composed of living, but rigid, human parts, each assigned to his special office, role and task, to make possible the immense work-output and grand designs of this great collective organization'(1).

Whatever the subsequent changes it may have experienced, the Egypt of the Pharaohs remains the prototype of a system in which the co-ordination and mechanization of human energy were largely impelled and guided by the central politico-religious authority. As soon as the polarizing force of the royal house weakened, the whole machinery collapsed. The European Middle Ages offer us another example of an energy system with very clearly defined social determinants. The rise of the water mill during the eleventh to twelfth centuries, led in the middle of the thirteenth century, to the saturation of all the

(1) L. Mumford: The myth of the machine, pp. 163 and 189, Harcourt Brace, New York, 1967.

available sites, whereupon the exploitation of wind energy helped to extend the effect of the hydraulic revolution to a small extent(1). In that period, the 'lords temporal were the journeymen and masters' of energy developments, though still completely bound by the constraints of a fuedal society. After an intermediate period that gave a brief chance to independent artisans, the hydraulic chain was restored and developed on a different basis at the turn of the thirteenth century and in the fourteenth and fifteenth centuries. There emerged veritable industrial complexes that combined - for instance the metallurgical purposes - the use of water mills with an increasing consumption of wood and an important logistic system to facilitate the transport of materials (horses, carters, etc.). At the same time an urban bourgeoisie developed, within which a veritable aristocracy based on wood came to the fore. The new energy system differed little from the previous one on the technical plane, but it nevertheless paved the way for a radically different mode of production: the capitalist mode. Here then we have a chain 'invented' in Greece more than 2,000 years ago (or perhaps imported from India by the armies of Alexander the Great), a chain that developed to some extent with the Roman Empire and then ebbed away only to proliferate centuries later in feudal Europe; its late flowering was but a medieval prelude to new developments under nascent capitalism.

These two examples bear witness to the primacy of the social, or even the political sphere in the application and rise and fall of energy systems. A deeper analysis would also reveal that the dynamics of energy systems are often reflections of the dialectics of socially contradictory systems of logic, and of the overt or latent clash of groups, classes, ... anxious to lay their hands on the sources and to gain control of the converters.

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(1) Cf. R. Philippe: 'L'énergie au Moyen-Age', Thesis, University of Maine, Angers, France, duplicated, pp. 1-807 (1981).

CHAPTER III: ENERGY SOURCES AND RESOURCES

I. THE CONCEPTS OF ENERGY SOURCES AND RESOURCES

A source of energy is one capable of supplying energy. The available quantities of energy constitute the resources. The real problem for man is to render energy fit for use, and the greater or lesser ease with which it can be harnessed may lead to different estimates of the resources.

Our earth is bathed in enormous quantities of energy, the main source being the sun. The sun is in fact a gigantic hydrogen bomb; it is the constant scene of the nuclear fusion of light atoms. The sun sends the earth an enormous 170,000 TW of energy, but the major part of that energy is reflected by layers in the atmosphere and radiated back into space before it can be absorbed. Only 40,000 TW are available for the evaporation of water (the earth's plant cover, free water surfaces, ...), 400 TW for other effects (movement of air, waves) and 40 TW for the fixation of energy needed by green plants (photosynthesis). The sun is thus the source of wind energy, of the energy stored in the (living or fossil) biomass, of wave energy due to differences in temperature between the upper and lower layers of the ocean, and of hydro-energy.

The internal heat of the earth, due to the radioactivity of rocks and hence of nuclear origin, can surface in volcanic regions (volcanoes, geysers, ...) and also manifests itself through a temperature gradient that increases with depth.

The quantities of energy contained in a source of energy do not really constitute a resource unless they are readily accessible and can be tapped. The most sought-after energy sources are those whose main energy content (expressed in unit weight or preferably in volume) is concentrated in large quantities in major deposits; cases in point are oil, coal, gas, uranium ore. In that case, we speak of <u>concentrated energy</u> as distinct from <u>diffuse energy</u>.

Even in the case of products with a high energy content, their degree of concentration in a given deposit (e.g. coal mixed with a greater or lesser amount of sterile material), the more or less favourable situation of the deposit determining their accessibility and easy exploitability, have a marked effect on the energy cost of their extraction and hence on their profitability. The latter also depends on the efficiency of technical extraction processes and on comparisons of the energy costs of different sources.

Other energy sources are naturally diffuse, for instance direct solar energy, the solar energy contained in the biomass, wave energy and geothermal energy (outside places of exceptionally high concentration). The need for concentration or collection (biomass) is a concomitant of exploitation and involves an energy expenditure that must be deducted from the quantity of energy obtained.

The more concentrated an energy resource, the less renewable it usually is. In other words, its present formation rate is much too slow to reconstitute a significant part of the much too rapidly depleted stock. Thus coal and petroleum are concentrated in precise locations of very ancient geological origin built up over millions of years; human consumption of energy will cause them to disappear almost completely within two or three centuries, and the amount of new coal and petroleum formed during that period is minute. These resources are therefore <u>non-renewable</u>.

Solar energy and the biomass derived from it, by contrast, are renewable resources, because the flow of solar energy is continuous. In general, solar energy must be harnessed immediately as there are few chances of storing it except in some forms of biomass, for instance in wood. We must however be careful not to confuse the renewability of an energy-containing product with that of the system that allows its production: thus the complete destruction of a forest and of the soil on which it grows would cause the disappearance of the resource, i.e. the timber which is a renewable source by definition.

II. VARIOUS TYPES OF ENERGY SOURCE AND THE CORRESPONDING RESOURCES

1. Renewable sources

With renewable sources, the resources practically inexhaustible, at least on the scale of human history(1), but we can only use the delivered flux and then only that part of the flux which we can capture (in the case of the sun) or collect (in the case of the biomass).

The sun with its power of more than 170,000 TW, is by far the most important source of energy accessible on earth. Even though a large part of that energy is absorbed by the atmosphere or sent back into space, the amount retained each day is about 8 kW/m^2. That energy can be exploited directly with the help of such captors as flat plate collectors or photovoltaic cells which convert solar energy into electricity(2).

Various types of energy derived from the sun represent resources that are often more important than direct solar radiation; even if they are diffuse, they are often easier to harness. They can be put into two classes: those based on climatic 'converters' (hydraulic and wind energy) and those based on biological converters (the biomass).

- Hydraulic energy is derived directly from solar energy. Solar radiation leads to the evaporation of the surface layers of the oceans. Water vapour, carried up by ascending currents of air forms clouds; subsequently it is precipitated back on to the earth in the form of rain. The world potential of hydraulic energy amounts to less than three million MW: its use is however generally more rewarding than that of wind energy because it is much more concentrated. The United Nations Statistical Yearbook estimated that in 1970 barely 10 per cent of this potential was being exploited. The countries in Africa, Asia and Latin America who made least use of it, accordingly have a significant development potential in this field. However, we must not forget the environmental problems that might be associated: the disappearance of arable valleys, the loss of forests, the loss of population from inundated sites, renewed or increased erosion of the soil up river ...

- Wind energy results from temperature differences in various parts of the atmosphere. The chief motive force is the temperature difference between tropical, equatorial and polar regions. Above the latter, the air cools and becomes denser whereupon its weight pulls it to the tropical regions. Here it is heated, carried up and then returned towards, and brought down over, the polar regions. The rotation of the earth, the irregularities of the terrain and the presence of oceans obviously complicate the behaviour of the winds.

(1) The sun will continue to shine for seven billion years!
(2) We must not overlook the 'passive' use of solar energy thanks to which we enjoy the light and heat of the sun.

The world potential of wind energy amounts to about 200,000 million kW. However, its small density and irregular behaviour make its exploitation a chancy business.

- Wave energy is derived from wind energy, and hence ultimately from solar energy. But its potential is limited and its capture raises a number of technological and practical problems that make its utilization in the immediate future highly doubtful.

- The biomass(1) represents a considerable energy potential, largely exploited by man for his food (endosomatic energy) and heat but also for such industrial products as textiles, timber, paper, cellulose for the chemical industry ...

- Tidal energy is a form of gravitational energy, the movement of the tides being caused by lunar attraction. The scope of that type of energy is limited and exploitable sites are few and far between (the height of the tides must exceed 5 metres). Moreover, it is generally believed that its potential represents barely 1 per cent of the world hydro-electric potential.

Region	Potential (10^6 kW)	Percentage of total	Harnessed in 1970 (10^6 kW)	Percentage of resources harnessed
North America	313	11	88	28
South America	577	20	13	2
Western Europe	158	6	93	59
Africa	780	27	6	1
Near East	21	1	2	8
South East Asia	455	16	8	2
Far East	42	1	21	50
Australia and New Zealand	45	2	7	16
USSR, Eastern Europe and China	466	16	40*	9*
Total	2,857	100	278	10

* Not including China.

WORLD POTENTIAL IN HYDRAULIC ENERGY, 1970 (In Stout, 1980).

(1) See glossary for the two distinct usages of the term 'biomass'.

Geothermal energy appears in two forms: one is diffuse, as we go down into the earth we record a constant increase in temperature (1°C on average for every 30-40 m); the other is concentrated and associated with pronounced volcanic phenomena (hot springs, ...). In addition, non-volcanic regions have been searched for privileged (better than average) sites; renewability sometimes poses delicate prognostic and technical problems, because the removal of material must be offset by restoration.

2. Non-renewable resources

This heading covers not only coal, oil, natural gas but also fissile nuclear fuels. The table below is based on estimates of the present-day state of non-renewable energy reserves.

	Fossil fuels					
Region	Solid fuels	Crude oil	Natural gas	Bituminous schists and sands	Uranium (without super-regeneration)	Total
Africa	382	556	213	86	209	1,446
Asia (not including USSR)	2,750	2,330	456	918	3	6,457
Europe (not including USSR)	2,720	60	162	123	49	3,114
USSR	3,510	352	610	147	not known	>4,619
North America	5,350	318	402	9,610*	446	16,126
South America	53	329	64	25	13	484
Oceania	485	10	26	10	105	636
Total	15,250	3,955	1,933	10,919	>825	>32,882

* According to the U.S. Bureau of Mines, the North American reserves in bituminous schists and sands are likely to have been greatly overestimated. At present, the exploitation of most of these reserves does not pay.

KNOWN WORLD RESERVES OF NON-RENEWABLE ENERGY

Unit: 10^{18} joules (In Stout, 1980)

The following table records world energy consumption, by source:

Source of energy	1960	1965	1970	1972	1980	1985	1990
Coal	65	66	71	70	84	90	97
Oil	48	68	102	113	140	155	174
Natural gas	19	28	43	48	60	71	81
Hydraulic and geothermic	7	10	12	14	16	18	20
Nuclear		<1	<1	1	13	36	67
Total	139	173	229	246	313	370	439

ENERGY CONSUMPTION BY SOURCE, 1960-1990

Unit: 10^{18} joules (In Stout, 1980)

This table shows clearly that the proportion of renewable (hydraulic and geothermal) energy sources is relatively small (of the order of 5 per cent at most).

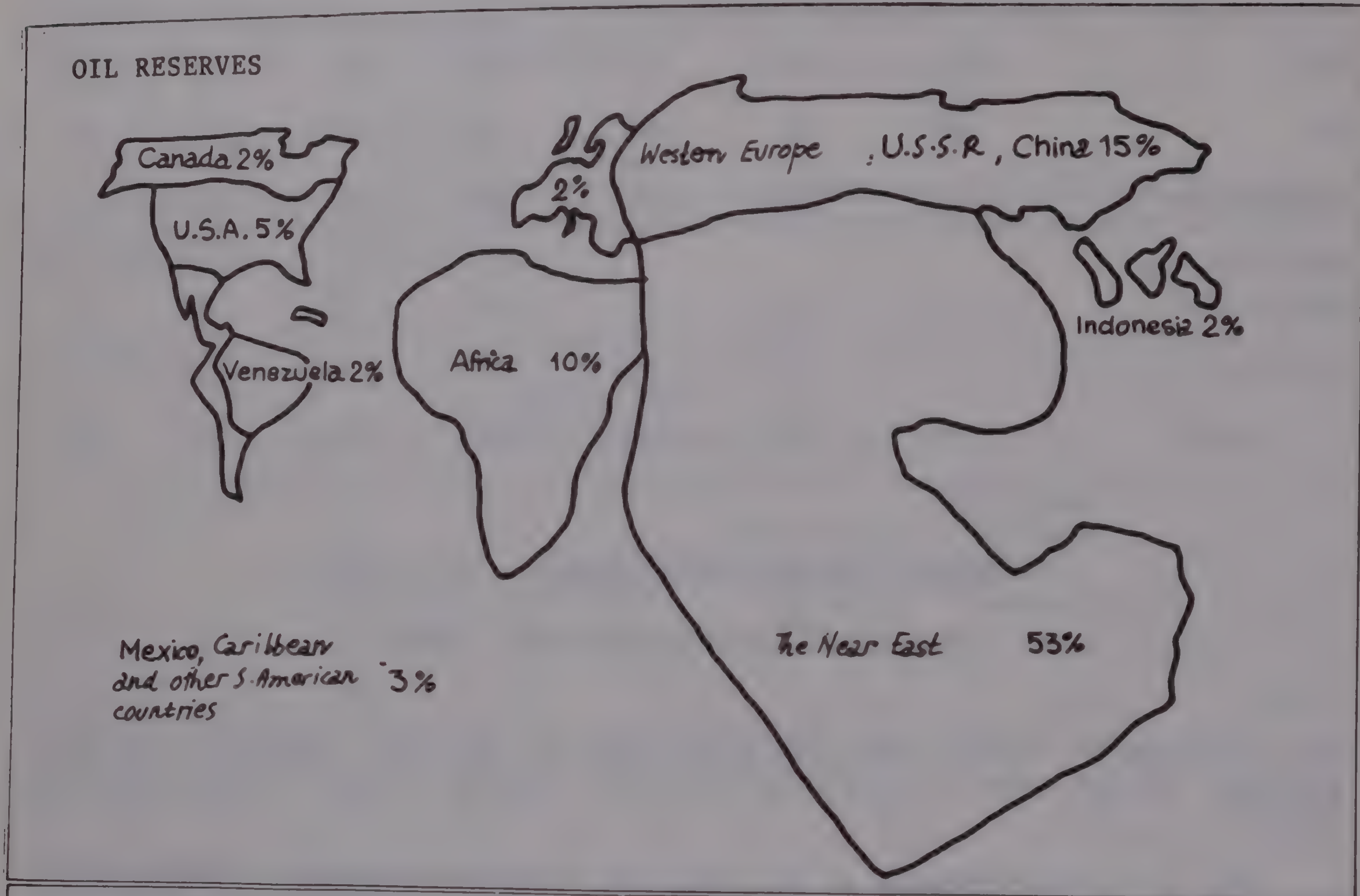
The world distribution of oil and coal reserves is shown on the maps overleaf. The table below gives the consumption by region in absolute values:

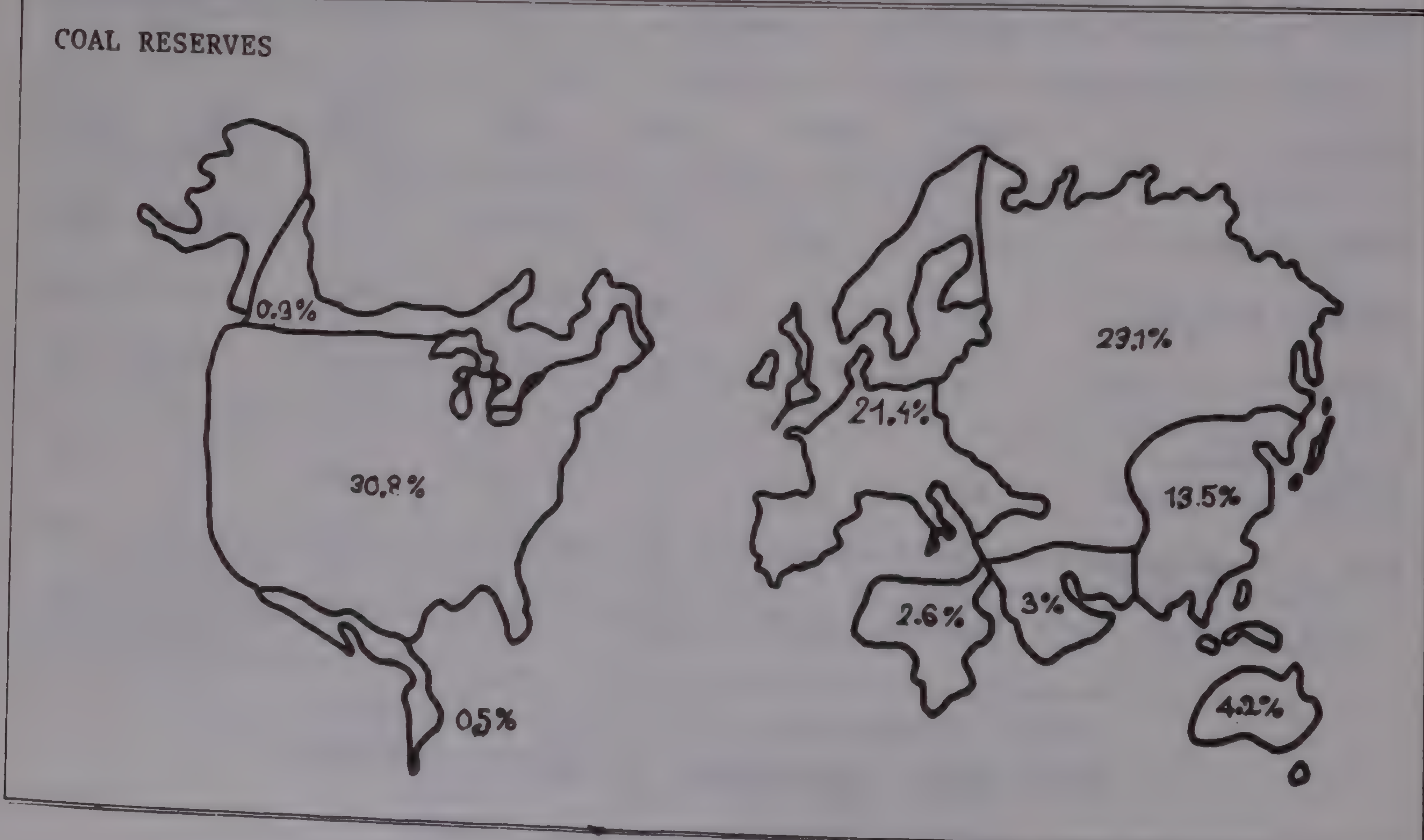
Region	1960	1965	1970	1972	1980	1985	1990
United States	47	56	71	76	91	109	129
Western Europe	28	36	49	52	66	79	92
Japan	4	7	13	14	22	28	36
USSR, Eastern Europe and China	41	48	61	67	86	99	115
Rest of the world	19	25	35	38	48	55	64
Total	139	172	229	247	313	370	436

WORLD ENERGY CONSUMPTION, BY REGION, 1960-1990

Unit: 10^{18} joules (In Stout, 1980)

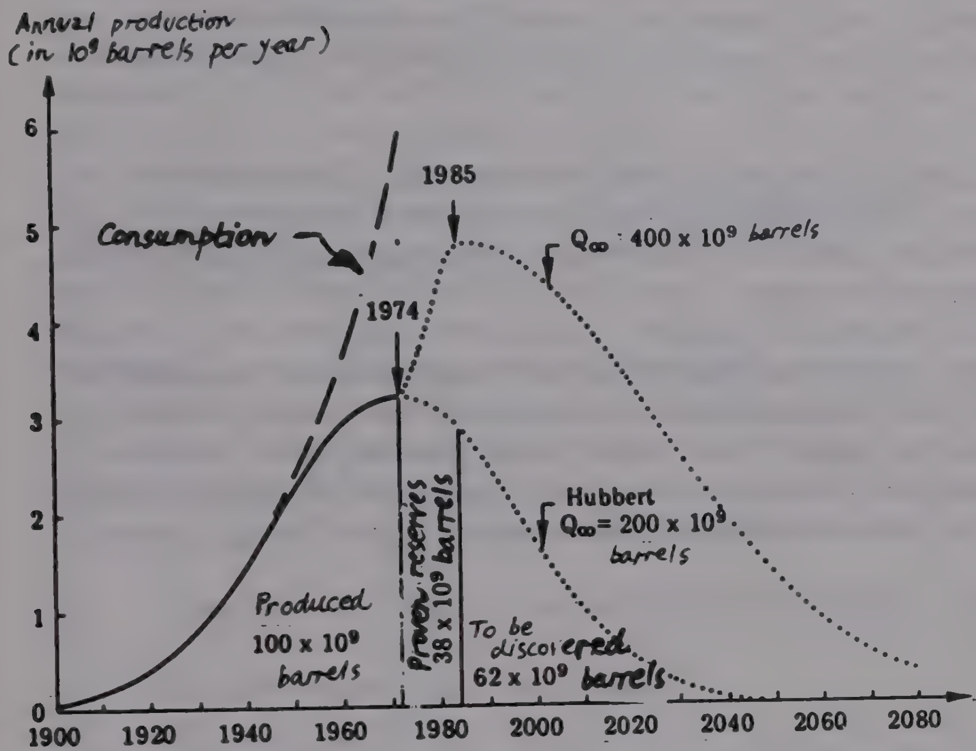
WORLD DISTRIBUTION OF OIL AND COAL RESERVES (In Stout, 1980).
The percentages for every region refer to the known and exploitable world reserves. The maps show what the world would look like if the size of each country were proportional to its reserves.





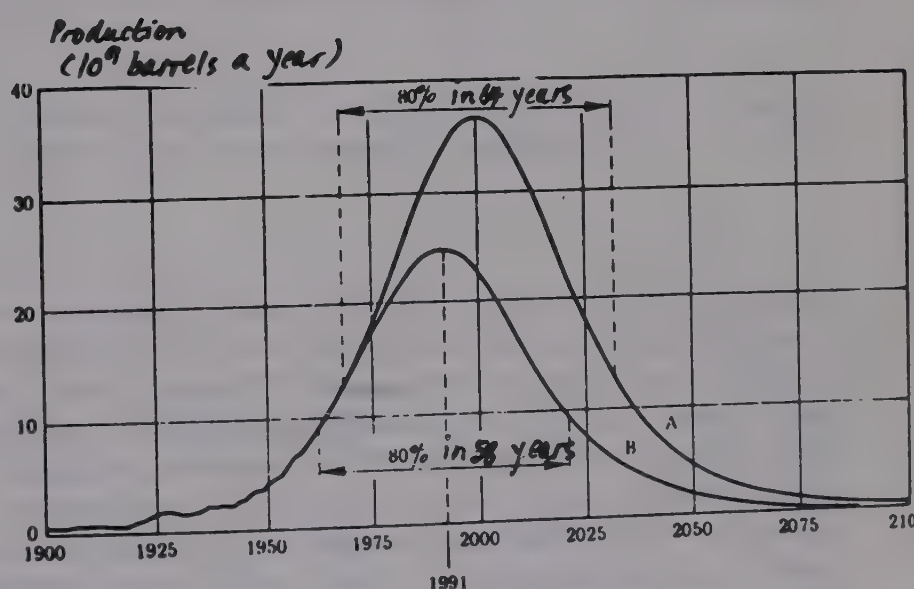
Geologists have drawn up rules for determining exploitation cycles of fossil fuel resources. Very schematically, we can put it that the exploitation cycle of a limited resource starts from zero, grows to a maximum and then drops back to zero: the exploitation cycle has the shape of a probability curve. From such curves drawn to date it is possible to extrapolate the curve for the rest of the cycle.

The figures below represent oil exploitation cycles based on the various hypotheses set out in the legends.



- Predictions of the total oil reserves (Q) that can be extracted from continental and off-shore deposits in the United States. The estimate Q = 400 x 10^9 barrels includes the Alaskan deposits, the continental shelf deposits and the deep off-shore deposits (down to a depth of 2,500 m) which cannot yet be exploited with current techniques (after Berg et al., Science, 184, 1974, p. 322).

- Estimate of oil that can be extracted from the lithosphere. The most favourable estimate, that by Ryman (Curve A) is of the order of 2,100 x 10^9 barrels or 330 x 10^9 t; that by Hubbert (Curve B) is more pessimistic: 1,350 x 10^9 barrels or 215 x 10^9 t. Note the short useful life of this source of energy on the assumption that the current rate of extraction will be maintained: 64 years in the more favourable case, production reaching a peak at the end of the century, and then declining. Although these predictions were made in the late 1960s, the data gathered during the last two decades have largely confirmed their validity (after Hubbert in Resources and Men, 1969, Ac. Sci. U.S., Freeman (ed.), p. 196)



OIL PRODUCTION IN THE UNITED STATES AND THE WORLD

From F. Ramade (1981)

The following points should be borne in mind in connection with these curves:

- As far as oil is concerned, first of all, the discovery of supplementary reserves (hypothesis B) representing 50 per cent of the estimate corresponding to hypothesis A merely extends the useful era of the exploitation of liquid hydrocarbons by six years(1).

- As far as coal is concerned, its useful era of exploitation seems to be much more promising; coal might well meet mankind's needs for another five centuries. The size of the reserves will certainly mean increased reliance on that resource, despite the problems of exploitation, transportation and utilization.

- As far as the reserves of nuclear fuels are concerned, the scarcity of uranium imposes the use of other technologies, such as fast breeders or nuclear fusion. If this switch is not made in the near future, there is a risk that mankind will run out of cheap minerals.

These brief indications show the need for greater reliance on renewable sources of energy and above all for the rationalization of the use of non-renewable resources. The problem is that the total reorganization of the systems of production and consumption dictated by that need cannot be achieved overnight. Moreover, it calls for considerable investments involving great expenditures of energy in turn.

(1) The useful era of a deposit or of the whole of a mineral resource is defined as the time of exploitation needed to exhaust 80 per cent of the existing reserves.

CHAPTER IV: USE AND MANAGEMENT OF ENERGY RESOURCES

Introduction

The manufacture of various objects and goods involves the elaboration of materials and energy by human labour; these three elements - material, energy and human labour - are as indispensable for highly mechanized manufacturing processes as they are in the rendering of services (e.g. travel).

Many examples show convincingly that classic economic analyses based on such concepts as monetary costs, supply and demand, interest, ... do not fully account for the way in which resources are managed and ultimately do not help the rational management of these resources. For a more detailed discussion of the whole topic, the reader might care to look at the remarkable contributions of such nonconformists as René Passet and especially of Georgescu-Roegen (Demain la décroissance). Their critical approach to economics rests, quite apart from theoretical considerations, on a system of material and energy balances. The establishment of energy balances for various systems (e.g. agricultural systems; methods of manufacturing a product, or energy in the form of a given vector) proves to be a valuable tool in the description of economic phenomena and hence in arriving at ideas about the control of present and future resources.

I. DRAWING UP ENERGY BALANCES: ECO-ENERGY ANALYSIS

Energy-balancing is based:

on the one hand on such quantitative expressions (rather than costs) as are used for instance to determine the energy consumption of a country by different sectors of activity;

on the other hand, on more precise studies, originally based on energy analyses but more recently on so-called eco-energy analyses.

1. Energy analysis

Despite generally wasteful attitudes by society at large or by certain circles, the various consumers of energy are not blind to the possibilities of making economies if only because of the financial benefits they bring. That is why the analysis of energy consumption has been practised for quite some time, essentially in industry and above all in sectors with a large energy consumption (metal extraction, chemical industry ...). Most often their computation of energy costs has been based exclusively on attempts to determine a theoretical efficiency limit in accordance with the laws of thermodynamics (see Appendix I). This practice is still common but attempts have been made to render it more precise. In fact, to obtain a piece of iron it is not enough to melt the mineral; a whole chain of operations must come first: mining the ore, crushing the ore, transport, ... so many operations necessitating the use of materials and machinery (bulldozers, trucks, ...) which not only consume energy in the present but also took up a great deal of energy when the machinery was being constructed. Strictly speaking, part of the energy used to build factories must also be included in the energy cost of the piece of iron ultimately obtained. To the so-called direct energy used in the manufacturing process, an indirect amount of energy must therefore be added. Numerous techniques facilitate the computation of the magnitudes capable of determining the energy cost (or specific energy demand) of every type of material or product.

Energy analysis helps, <u>inter alia</u>, to establish:

(1) The efficiency of a process or of a reaction in relation to the theoretical thermodynamic limit. The answer can be expressed as a fraction of 1 or as a percentage.

(2) That, whenever it is possible to retrace the manufacturing history of a product or type of product, the improvement in manufacturing techniques will generally be found to go hand in hand with a decrease in energy costs. Examples can be found in the manufacture of most industrial products (steel, cement, artificial fertilizers).

(3) That biotechnological procedures at (relatively low) temperatures compatible with the maintenance of life (e.g. fermentation) and based on the action of enzymes are preferable to reactions needing high temperatures.

(4) That the production of energy in a given form and hence constituting a particular vector (e.g. electricity) has a specific energy cost. Thus electricity produced from fuel oil in a power station does not represent more than about a third (secondary energy) of the energy content of the fuel oil (primary energy).

All the procedures used in the manufacture of a given product for a given purpose should be taken into account. For example, electric trains are more efficient than diesel trains:

> with electricity, the efficiency of the motor is of the order of 0.9, so that it is possible to recover 9/10ths of the third of the energy contained in the fuel oil, or about 30 per cent;
>
> the efficiency of the diesel engine is very low, and does not allow the utilization of more than about 15 per cent of the energy of the fuel oil. The problem becomes more complicated if the train is heated: for heating, electricity has an efficiency of just 30 per cent, while that of the fuel oil is 100 per cent ...

2. <u>Eco-energy analysis</u>

This method of energy balancing (or rather of energy budgeting) rests, in addition to energy analysis, on the description of systems with the aid of energy flow charts currently used in ecology (whence the term 'eco-energy'). In fact, ever since Lindemann presented the first energy flow model in 1942, this concept has been chiefly applied to such natural systems as have been left relatively unchanged by human intervention. This, for instance, was the approach used in the first monographs on ecosystems underlying the didactic presentation of ecology (Teal, 1957-1962, Odum, 1957 ... see also the various ecology handbooks, especially Dajoz, <u>Précis d'Ecologie</u>, Dunod and Duvigneaud, <u>La synthèse écologique</u>, Doin).

It was not until 1971-1973 that energy flow charts were first drawn up to account, in man-controlled systems, for energy contributions other than solar energy(1).

(1) W. Kemp, 1971, 'The flow of energy in a hunting society', in <u>Scientific American</u>, 224, pp. 105-115;
R. Rapaport, 1971, 'The flow of energy in an agricultural society', in <u>Scientific American</u> 224, 3, pp. 117-132;
E. Cruz de Carvalho and J. Vieira Da Silva, 1973 - 'The Cunene Region: Ecological Analysis of an African, agropastoral system', in F. Heimer (ed.) <u>Social Change in Angola</u>, Weltform Verlag, Munich, pp. 145-192.

The most famous study, which did most to help the spread of this type of analysis was that of D. Pimental et al. (1973)(1) which lists the overall energy expenditure on maize cultivation in the United States.

The following discussion of some of the most important studies will show the reader some of the difficulties involved. The possible uses of the discussion for teaching purposes will be examined later (see Appendix II).

II. CASE-STUDIES IN ECO-ENERGY ANALYSIS

1. Crops

As an example we shall now look at the work of D. Pimentel et al. (1973) on maize cultivation in the United States. That study is based on agricultural statistics for the whole of the United States; the results are given at intervals of five years, from 1945 to 1970.

Table 1 examines the first and last year covered by the study. It lists the various types of energy expended on the cultivation of one acre of maize:

in the form of human labour which is derived from the potential chemical energy of food, the authors assigning it a value of about 550 kcal per hour of work, which represents the total energy expenditure (including the energy expenditure of the human organism which would occur even in the absence of work);

in the form of machines and engines whose energy is necessarily 'contained' in the material of which they are made. The authors have used the figures published by Berry and Fels who have worked out that it takes 31.968×10^6 kcal to build an automobile weighing 3,440 lbs. (ca. 1.36 metric tons). That value was applied to the total weight of the material used, 6 per cent was then added for maintenance and the sum divided by the number of years it takes to amortize the car (ten years). By considering the quantity of fuel used and the energy value per unit, one can easily compute the energy needed;

for drying machines, electric equipment, transport (of machinery and materials to the fields and of maize to its destination). This energy has been computed solely in respect of direct consumption;

for irrigation. The figures quoted do not give the energy expended on irrigating one unit of surface area but an average figure for the United States, established on the basis of the percentage area covered by irrigated maize crops (ca. 3.8 per cent);

in the form of fertilizers and other products, their share in the total energy cost (energy expenditure per unit weight) being computed with the help of coefficients obtained by energy analysis. The enormous expenditure on nitrogen is explained on the one hand by the fact that the quantities used per unit surface have increased enormously from 1945 to 1970 while, on the other hand, the unit energy cost remains high; the manufacture of nitrates involves electro-chemical processes that swallow up energy, whereas phosphate or potassium fertilizers are obtained by normal mining methods;

(1) D. Pimentel et al., 1973, 'Food production and energy analysis', in Science, 182, pp. 443-449.

	1945	1970
Human labour	12.5	4.9
Machines	180	420
Fuel	534.4	797
Drying	10	120
Electricity	32	310
Transport	20	70
Irrigation	19	34
Fertilizers		
- nitrogen	58.8	940.8
- phosphorus	10.6	47.1
- potassium	5.2	68
Insecticides and herbicides	0	22
Seed	34	63
Total inputs (I)	925.5	2,896.8
Harvest (O)	3,427.2	8,146.8
Ratio O/I	3.7	2.82

ENERGY BALANCE FOR MAIZE CULTIVATION IN THE UNITED STATES (after D. Pimentel et al., 1973). The values are given in thousands of kilocalories per cultivated acre (1 acre = approx. 0.4 ha).

the calorie content of the seed and the crop has been put at 1,800 kcal per lb. or 3,979 kcal per kg.

The study shows that between 1945 and 1970, quite apart from an increase in the yield per acre from 34 to 81 bushels (1 bushel = 64 U.S. pints or 36.4 l), the yield from the investment of energy in maize cultivated has been dropping, because the O/I ratio giving the energy efficiency of the system has dropped from 3.7 to 2.82. One could also put it by saying that whereas it took 1/3.7 = 0.27 kcal of energy to obtain one kilocalorie of maize in 1945, it took 1/2.82 = 0.35 kcal in 1970. J.R. Mercier(1) has called that quantity (which is the inverse of the O/I (output/input) ratio) B.U.E.R. (besoin unitaire en énergie rare = unit need for rare energy).

It should be pointed out that not all the kilocalories mentioned here are of the same kind:

the kilocalories corresponding to the potential chemical energy of maize are 'food calories';

food is the basis of the kilocalories supplied to the system in the form of human labour;

the rest comes from classic energy sources, essentially made up of fossil fuels.

Since the publication of the early results, similar computations have been made for various other crops, all based on the same principles (see table below).

Crop	Yield (kg/ha)	Straw (kg/ha)	Energy (10^3kcal/ha produce)	Protein (kg of protein per kg of produce)
Soft wheat	3,000	3,000	4	0.115
Dry barley	2,000	2,000	4	0.068
Dry oats	1,500	1,500	4	0.068
Peas (irrigated)				
(early)	6,500	-	0.63	0.058
(main crop)	11,000	-	0.63	0.058
Potatoes (irrigated)				
(early)	12,000	-	0.76	0.021
(main crop)	19,000	-	0.76	0.021
(late)	13,000	-	0.76	0.021
Lettuce (main crop) (irrigated)	8,000	-	0.11	-
Maize (irrigated)	4,000	4,000	4	0.095

ENERGY COST OF SOME INTENSIVELY GROWN CROPS IN FRANCE

(in J.R. Mercier, 1978)

(1) J.R. Mercier, 1978, Energie et agriculture, Debard, Paris.

Many authors have presented eco-energy analyses covering agricultural practices in industrialized countries. The reader might like to consult G. Leach (1976) who, inter alia, examines the use of energy for crop-growing in developing countries and gives a host of analytical results for various traditional civilizations engaged in itinerant or subsistence farming, relying exclusively on human labour and possibly on animal traction and also on some degree of mechanization.

2. Farming

Farms and smallholdings (including co-operatives) can:

either engage in monoculture in which case the preparation of an energy balance is as described above;

or else they can use a more complex system of stock breeding and milk production (which involves the feeding of animals, pastureland or the growing of fodder), or mixed systems with several crops and a section devoted to stock breeding; in that case, eco-energy analysis must allow for as many headings as there are types of production, though it is still possible to determine the overall efficiency of the system by calculating the O/I ratio or its inverse.

Leach (1976) has published a table giving the results for different types of farming in the United Kingdom in 1970-1971, and J.R. Mercier in his Energie et agriculture (1978) quotes a good many of these results adding some of his own and tries to establish by comparisons that farms of a biological type are the most energy-efficient.

As an example, we shall now look briefly at a very detailed study by P. Duvigneaud et al. (1980) of farming in the Ardennes (Belgium), showing how energy balances can be drawn up at farm level (cf. Appendix II). We shall also be looking at a comparative study of two types of goat-rearing farms (in Corsica).

(a) A farm in the Ardennes

The 27.27 ha farm is organized for the production of beef and milk; it keeps an average of 58 animals (27.6 tons of biomass live weight), or about two animals per hectare.

The cattle feed consists almost exclusively of the harvest from 14 ha of permanent grassland and of 13 ha under cultivation (grass, oats, barley, ...).

The permanent grassland is used 210 days a year and provides 91.980 kg of grass (dry weight), a figure computed as follows:

fresh grass: 22 per cent dry matter;

each cow or heifer in calf needs 55 kg FM/day or 12 kg DM/day (FM = fresh matter; DM = dry matter);

each bullock or cow not in calf needs 40 kg (FM/day or 9 kg DM/day;

each calf (not out to grass for more than 60 days) needs 30 kg FM/day or 6 kg DM/day.

Thus 23 cows or heifers in calf, 14 bullocks or heifers not in calf and 21 calves take out approximately 92 tons DM from the 14 ha of grassland, or 657 kg DM/ha/per annum. On the hay meadow (7.8 ha), 54 t DM of hay are cut for consumption in the farmyard. Cereal crops (5.2 ha) provide 20 t DM of grain and 12 t DM of straw.

The total plant matter consumed by the cattle or 179 t DM per annum represents at the rate of 4 kcal/g 716 x 10^6 kcal. This energy stock gives rise to that 41.2 x 10^6 kcal of animal produce, mostly for export.

Returned to the fields are, on the one hand, the non-consumed parts of the crops, and on the other hand the excreta of the animals. These are released on to the pasture directly or, mixed with straw, as manure.

This agro-ecosystem relies on the amount of solar energy available on the farm in the course of the year, or 216,000 x 10^6 kcal, of which a very small part, of the order of 1,650 x 10^6 kcal goes into primary production to end up as usable animal produce of about 40 x 10^6 kcal. The respiration of the animals uses up 300 x 10^6 kcal!

To operate that system man must inject fossil energy in direct or indirect form: 30 million kcal for tractor fuel; 48.2 million kcal for fertilizers; 2 million kcal for electricity and 45 million kcal for his own firewood.

(b) Comparison of two goat-rearing farms in Corsica (J.P. Deleage, N. Sauget-Naudin and C. Souchon, 1979)

One of these two stock farms was of the traditional type based almost exclusively on the exploitation of scrubland, the other had been modernized to grow lucerne on irrigated fields.

The table allows us to compare the main characteristics of these two systems (unit: 10^6 kcal). It seemed justified to extend the use of these figures to the whole of the valley since, though the modern stock-rearing farm was unique, the results of the traditional stock farm were typical of any of the 15 farms of the same type in the region. The resulting figures were completed by taking into account free-grazing herds (cattle and pigs) and by a study of the winegrower's co-operative.

3. Rural systems at regional level

Several regional studies have been published, especially for African contries(1).

(a) Monograph on the structure and function of systems. The case of Chingo (Angola) and of Thysse-Kaymor (Senegal)

Eco-energy analysis has made it possible to show what factors determine the operation of these two ecosystems. It considers the prevailing relationships between the human community and the environment and also within that community, both in respect of the appropriation of resources and energy flow and also in respect of resource and energy management.

(1) Cahiers du Germes, No. 3, 1980, Matière et énergie dans les écosystèmes et les systèmes socio-économiques, pp. 1-542, Paris.

Production phases	Headings	Farm No. 1 Traditional	Farm No. 2 Modern
Energy inputs	Investments (Mechanical + fertilizer)	21	109.5
	Renewable En. (including seed)	64	21.7
	Direct fossil En.	16.7	299.1
	Total inputs	108.3	430.3
Primary production	Scrub grazing	1069	525
	Plant production for the use of animals	90	836
	Plant production for human consumption	10	1.5
Secondary production	Goats	66.1	82.5
	Others	1.3	3.7
	Output/Input ratio	0.72	0.20
	Efficiency of human labour	23.8	22.2
	Self-consumption	67%	40%
	Total produce for human consumption	77.4	87.7

COMPARISON OF TWO STOCK-REARING UNITS IN CORSICA

(Unit: 10^6 kcal)

In the case of the Chingo ecosystem (Angola), the energy balance drawn at the level of the human community reflects the regulations that human activities can introduce into the operation of a natural ecosystem.

The transfer of energy and of biomass in the Chingo ecosystem clearly demonstrates the existence of a large number of ecological niches and hence the diversity of this traditional system. Its density also reflects the large number of trophic levels and their interrelationships, the considerable accumulation of structures and functions or, in other words, the considerable storage in that ecosystem of energy utilized in the form of biomas.

In the Thysse-Kaymor ecosystem (Senegal) by contrast, the decrease in diversity, due essentially to imported technologies aimed at increasing production for export has led to simplification and a tendency to underdevelopment. Here the great efficiency of human labour (unit energy produced by unit of labour energy = 41.5) is greatly reduced since, if all the energy needed for this type of agricultural production is taken into account, the ratio drops to 4.0.

(b) <u>Comparison of two different farming systems in the same environment. The case of Cunene (Angola)</u>

The systematic comparison of a traditional ecosystem with a modern ecosystem in Cunene has shown that, from the ecological and even from the human point of view, the traditional system is the more highly developed. It is in fact capable of maintaining diversity and a considerable energy flow while relaying an important part of that flow through the human biomass:

- traditional pastoral system: 15.4 (units of energy produced per unit of
- ranching system : 7.4 human biomass)

The modern system is heavily loaded with inputs due to modern technologies. Similar comparisons have been made for different environments, and it was found that agricultural ecosystems have widely different efficiencies in terms of human labour, ranging from 17.6 to 41.5 units of energy produced per unit of labour.

(c) <u>Establishment of projective models (simple simulation) based on eco-energy analysis. Examples: the M'Pourie plain (Mauritania) and the Fissel region (Senegal)</u>

The most recent studies, still based on the eco-energy analysis of agricultural systems, have shown that it is possible to predict an increase in the available per capita energy from developments relying exclusively on local resources. In his study of the M'Pourie plain, which has a semi-arid climate with a rainy season from June to October and a dry and cold season from November to March, and a graminaceous vegetation consisting of <u>Cenchrus biflorus</u> together with some cyperaceous and leguminous plants, the author evaluates a short-term ecological plan based on better use of local resources (draught animals, natural fertilizers, etc.), of the human potential and, finally, on an extension of the arable area.

With this improved management of the ecosystem, the energy efficiency of human labour increases from 44 to 60, and the energy flow through the population increases from 47 to 64 kcal/unit of human biomass. As a result, the population becomes self-sufficient in sorgho and meat. The demand for animal fodder can be satisfied as well. The efficiency of the total energy invested is more than doubled, rising from 1.20 to 2.70.

J. Vieira Da Silva, in a study of the Fissel region (Senegal), situated in the groundnut zone, has used the energy flow of the ecological system to show that a strategy based on local resources alone can help to treble the energy contribution of each individual.

The results of the eco-energy analysis of the present operation of the system (essentially based on groundnut cultivation) are summarized in an energy flow chart setting off inputs against outputs. From that chart, and on the basis of various hypotheses (use of fertilizers, introduction of millet, use of Acacia albida, ...), it is possible to draw up a quantified medium-term picture of a development plan based on the various options. With the strategy proposed by the author, it should be possible to:

increase the efficiency of human labour from 19.9 to 24.7;

nearly treble the import capacity;

release produce for export (groundnuts but also animal products).

4. Agricultural systems in various countries

Eco-energy analyses of systems are available for various, mainly industrialized, countries, with an appropriate statistical apparatus. Such studies have been made notably in France (R. Carillon at CNEEMA, J.P. Deleage and C. Souchon of the EDEN group), in the United Kingdom (G. Leach) and in Israel (Stanhill).

5. Cities and ecosystems

(a) The city as an ecosystem

Most ecological studies of the urban phenomenon have borne essentially on changes in the natural environment caused by the development of towns and on the consequences of great concentrations on the physical and mental health of human populations. In that type of analysis, the emphasis is placed mainly on what might be called the urban crisis:

increasing traffic problems;

systematic and massive week-end flights from the towns;

delinquency, criminality, drugs;

laborious commercial channels;

refusal by people to live in tower blocks or high-rise flats;

total loss of conviviality;

increasingly insoluble problems of waste disposal and energy supplies;

increasingly unmanageable public services;

reluctance by rural or provincial youth, formerly fascinated by the attractions of the provincial or national capital, to leave their places of origin;

such 'urban diseases' as obesity, insomnia, stress, rhinopharyngitis due to pollution, ...

Here we shall be using a different approach and analyse the city as an ecosystem and, in particular, examine the energy flow through it.

Now, a city can be considered an ecosystem just as a forest can - it is a functional system with biocoenoses (mainly human populations and reduced animal and plant populations), a particular climatic environment and a metabolism (flow of energy and matter, a hydraulic cycle, etc. ...).

However, there are important differences between urban and natural ecosystems; in a city there is no, or very little, primary production; when it does occur it is relatively insignificant compared with non-biological (but cultural) processes employed with a rapidity that sets them off clearly from natural ones. As a result, it is difficult to apply some ecological concepts or laws to urban ecosystems, while others demand a complete redefinition. If that is done, it becomes possible to show how an urban ecosystem functions and to give a better account of the relationship between cities and the regions in which they are located.

(b) Energy in cities

To be at all useful, energy balances must necessarily be drawn up in accordance with the principle of the conservation of energy (first law of thermodynamics). To that end, all we need do is to determine the sources of energy and the stages of its transformation and exploitation. In other words, we must analyse the energy flow. We know that it is a flow, on the one hand because the urban ecosystem is an open system (in the physical sense) so that it is possible to consider energy inputs and outputs; on the other hand, because it is governed by the second law of thermodynamics: no energy can be transformed without degradation, i.e. without a change from a concentrated into a dispersed form.

All studies of urban ecosystems must pay particular attention to the distinction between gross, net and primary energy:

Gross energy is the total amount of energy present at any stage of the energy transformation chain.

Net energy is equal to gross energy minus the energy needed to maintain (renew) the gross energy and to utilize it (extraction or removal, transport, assimilation, ...). It is a real quantity which can be transformed and used for specific ends.

Primary energy is the gross energy available after the transformation of solar energy by plants - the first links in the transformation chain of natural ecosystems.

The respective orders of magnitude of gross and net energy can differ considerably and depend on the organization of each system; in a sense, the difference can serve as a measure of the efficiency with which towns husband energy.

For the individual consumer all that matters is the net energy available to him. However, for the study of a system and its relationship with other systems, we must know from what type of gross energy the net energy is derived.

In the case of urban ecosystems the nature of the energy supply, mainly fuels, complicates matters, because depending on the point at which the fuel is introduced, it can be treated either as a source of gross or else as a source of net energy.

(c) A case-study: the city of Paris

As an example we shall now examine(1) the essential results of a full study of the energy flow sustaining the metabolism of the city of Paris. That energy flow is divided into a natural energy flow and a subsidiary, imported, energy flow.

Natural energy	$10,377 \times 10^3$TJ
Alimentary energy (primary energy)	64×10^3TJ
Energy of 'fuels' (primary energy)	589×10^3TJ

ENERGY FLOW IN THE PARIS ECOSYSTEM (after B. Dambrin, 1982)

Over and above a significant amount of natural energy, the urban ecosystem is a consumer of energy in the form of foods and fuels; this imported energy represents about 6 per cent of the natural energy, petroleum products (58.8 per cent) taking pride of place over gas (19.8 per cent).

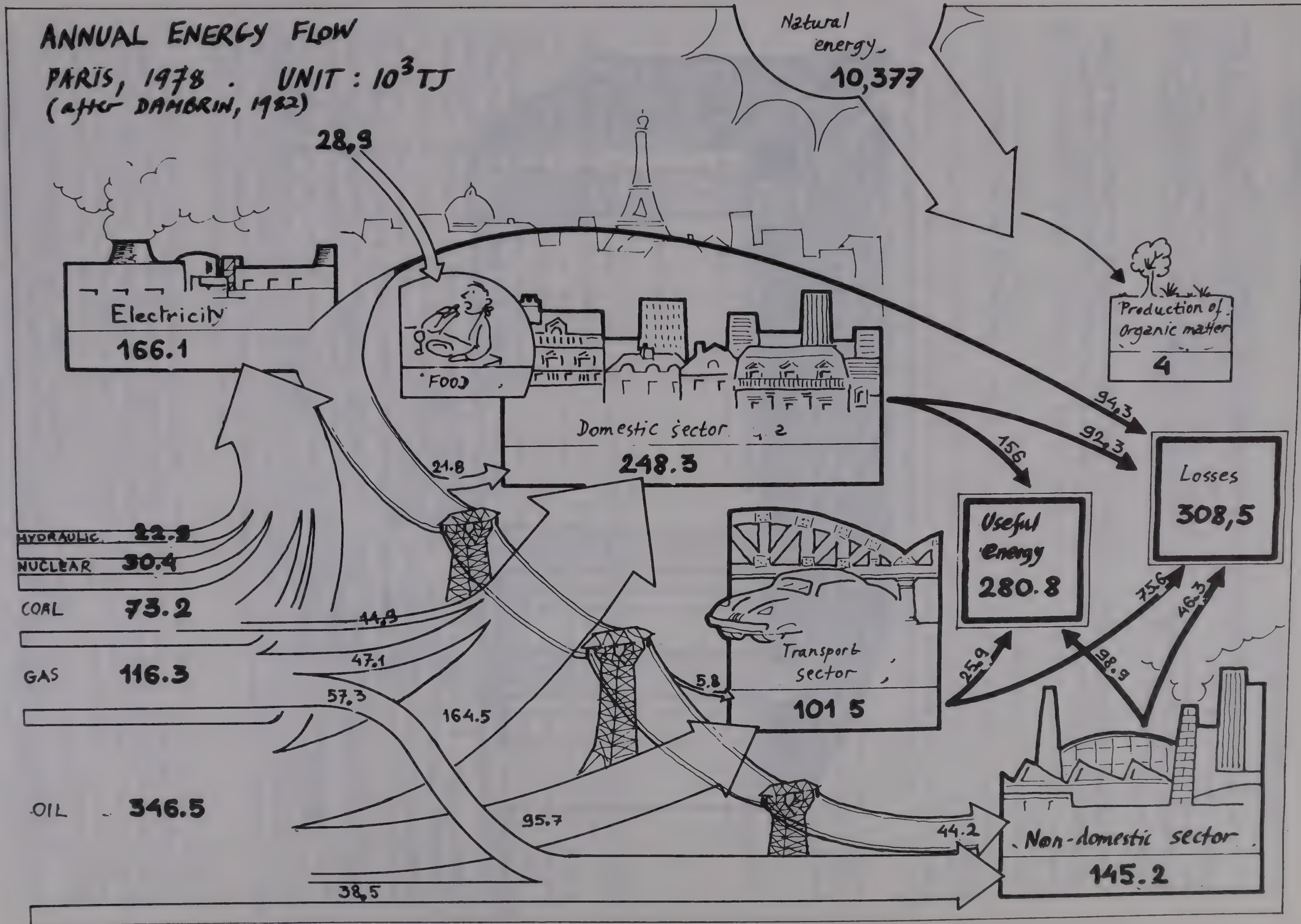
Another characteristic of the urban ecosystem: very little natural energy goes into the water cycle or into the production of organic matter (3.6 TJ/ha and 0.05 TJ/ha respectively) as compared with 15 to 20 TJ/ha and about 0.2 TJ/ha in natural ecosystems in the environs of Paris; by contrast, the transfer of heat by convection is much more intense: 15.1 TJ/ha as against just a few TJ/ha in the countryside round Paris. That characteristic gives man enough elbow room to run an urban ecosystem.

(d) Energy dependence

It has been shown that the urban ecosystem is wholly dependent on the outside world for all its supplies: food, energy, materials, space. It is equally dependent on the outside for the removal of some of its products and especially of its waste. In that respect, it is a typical consumer system. Like the trophic system of classic ecology, the urban ecosystem behaves as a secondary producer, with all the problems this state of affairs entails for the student. From a functional point of view, two links of the chain, namely 'primary producer' and 'decomposer', remain indispensable, but have moved outside the system.

On the energy plane, the dependent character of the urban ecosystem is reflected with particular sharpness in the fact that it needs a fuel 'subsidy'. More precisely, in the case of Paris, 79 per cent of the energy supply is obtained from resources that cannot be renewed in the short run; we are entitled to ask, therefore, if this quantitative and qualitative organization of energy is compatible with the maintenance of the city as an ecosystem, and *a fortiori* with its extension or the creation of new urban centres.

(1) Other studies have been made especially of Brussels and Charleroi (Belgium) and of Hong Kong. The Paris ecosystem has been studied by B. Dambrin, 1982, Thesis, University of Paris VII.



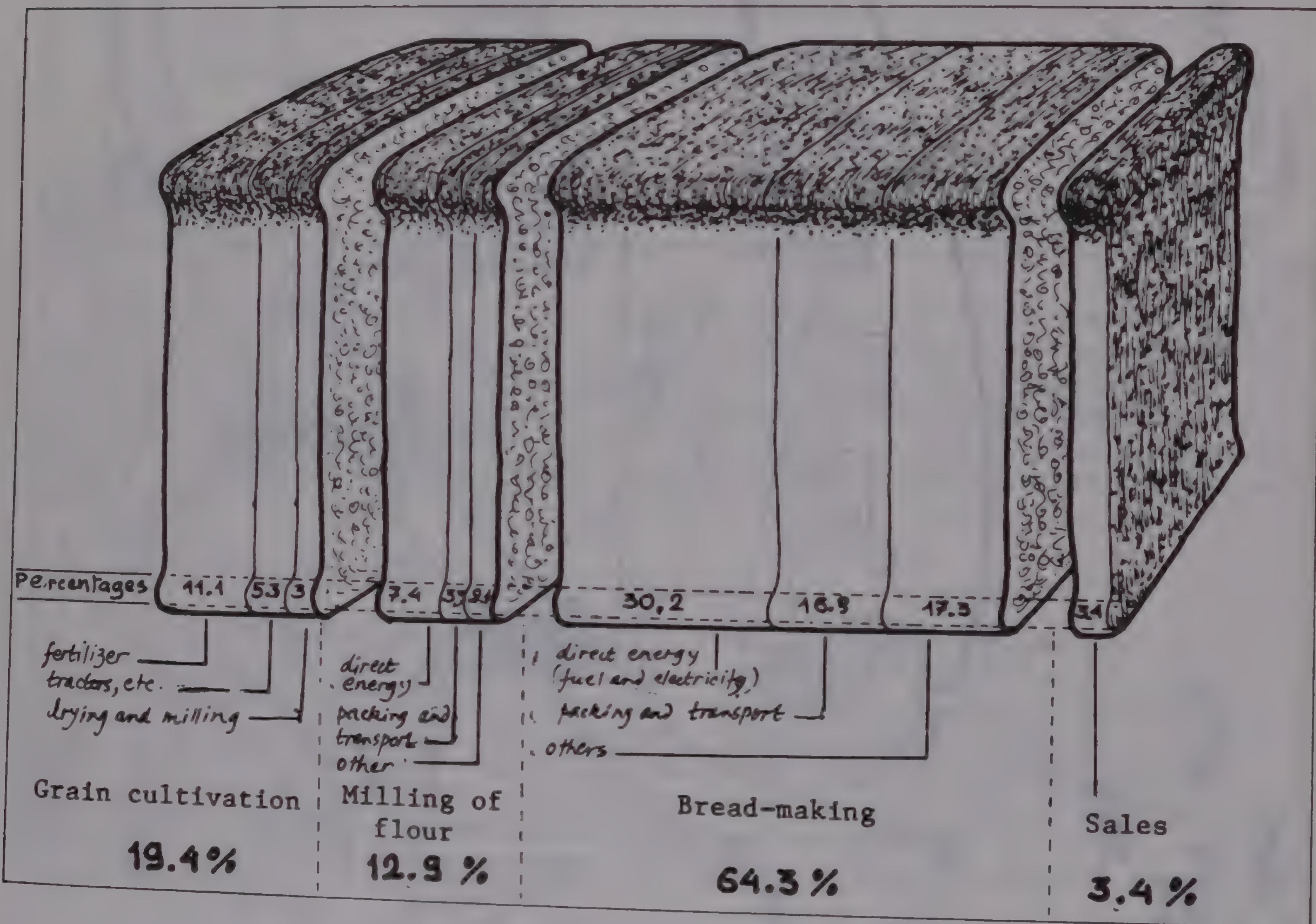
ANNUAL ENERGY FLOW
PARIS, 1978 . UNIT : 10^3 TJ
(after DAMBRIN, 1982)
Natural energy
10,377
28,9
Electricity
166.1
FOOD
Domestic sector
248.3
Production of organic matter
4
94,3
92,3
156
Losses
308,5
Useful Energy
280.8
Transport sector
101 5
25.9
75.6
46.3
98.9
Non-domestic sector
145.2
HYDRAULIC 22.9
NUCLEAR 30.4
COAL 73.2
GAS 116.3
OIL 346.5
21.8
44,9
47,1
57,3
164.5
5.8
95.7
44.2
38,5

6. Production methods

The use of eco-energy analysis of production methods is indicated in many cases, especially when it comes to particular crops. Thus the energy costs of the 'comparative production of ethanol and methanol from renewable resources' have been computed and the reader will find the details in La valorisation de la Biomasse, 1981(1).

Another example, that of bread in the United Kingdom (illustrated below) shows the distribution of the energy needed to produce this type of food together with the energy cost: 1 kg of bread ultimately 'costs' nearly 0.5 kg of oil(2).

Similar results are also available for the production of milk and allied products.



(1) J.P. Deleage, J.M. Julien and C. Souchon, 1981, La valorisation de la Biomasse: étude du cas de la France, E.D.F., Paris.
(2) After Leach, 1976.

7. Conclusion

On the basis of these concrete examples, the aims of eco-energy analysis can be formulated as follows:

determining the operation of characteristic human systems in various eco-regions, and of various ways of life and economic practices;

comparing various types of agriculture in regions with diversified methods of exploitation (e.g. by their level of exploitation or co-operation);

specifying the role and efficiency of energy investments in different systems of production;

assessing the efficiency of human labour and its contribution to development, i.e. deciding whether the energy is being applied not only to best productive effect, but also to improve the quality of life;

establishing the share of the exploitation of natural resources in the production of food and in the direct or indirect elaboration of other consumer goods; assessing the role of social and cultural practices and of various methods of control on the flow and utilization of energy;

using established simulation models to make predictions on the basis of hypotheses to be framed, always starting from concrete initial data.

III. ENERGY AND DEVELOPMENT

There is no doubt that the nature and the intensity of the exploitation of energy largely determine the kind of society we live in. This is true of all past societies as well. At the end of the eighteenth century, when James Watt's steam engine began to play an important role in industry in the United Kingdom, Europe was irrevocably drawn into the industrial revolution. The large-scale exploitation of coal was one of the main bases of British and European economic predominance in the nineteenth century. Petrol and the internal combustion engine, and the development of electricity supply systems enabled the United States and Europe in their turn to dominate the market economy. The recent development of such new forms of energy as nuclear energy has been continuing that story. From the Second World War until 1973, in the Northern Hemisphere, economic development seemed to go hand in hand with a growing consumption of primary energy. Per capita energy consumption is considered a major indicator of development and there is a tendency to believe that the progress of civilizations is based on the mobilization of ever increasing sources of energy: to this day, despite the economic crisis, many people continue to think that they must copy the big industrial countries with their hyperdeveloped energy system.

The non-industrialized countries, most of them in the Southern Hemisphere, also need energy, but have extreme difficulty in gaining access to fossil resources. Generally speaking, increasing consumption is considered a major condition of, indeed a key to, economic development. Thus, among the 18 indicators used by UNSDRI(1) to define the state of development of countries,

(1) United Nations Social Development Research Institute. 'Contents and measurements of socio-economic development - Report 70-10 - Geneva'.

two involve energy directly: the consumption of electricity and the mean *per capita* consumption of energy. Most international bodies (the World Bank, the FAO, etc.) also use energy indicators. However, these indicators do not generally include such non-commercial resources as firewood, which nevertheless plays a vital role in most countries of the Third World. Moreover, these indicators simply define amounts of crude energy: they tell us nothing about methods of production, efficiency, and ultimate use.

There remains the fundamental question of whether or not development is absolutely dependent on high energy investment. The answer is evidently that it is, particularly, when one considers the extremely low energy availability which is the lot of many Third World countries. Here, the problem is providing the population with their most elementary energy needs (cooking of food, transport, ...). However, the answer must be much more qualified when the consumption of energy is directly linked to the use of more or less sophisticated technologies or channelled into sectors devoted to exports to the industrialized countries.

The agro-alimentary sector often provides striking examples of the wrong use of energy-costly technologies (irrigation by pumping rather than by gravity; drying of crops by various industrial methods rather than by simple exposure to the sun, ranching rather than traditional farming, ...). Many poor countries in Africa and Asia exhaust their resources in exporting cash crops, the financial return from which no longer balance the increasingly large oil bills.

The only source of energy to which the largest part of the population of these countries has access is timber and animal and vegetable waste: wood, charcoal and waste represent a worldwide source of energy amounting to close on 600 million tons of oil equivalent. More than half of mankind is therefore dependent on the biomass for cooking of food.

Very often, this use of the biomass, which leads to dangerous pressure on forest ecosystems, is not enough to supply even the elementary needs of the population. According to the FAO more than a thousand million human beings in Africa, South-East Asia, Andean and Central America are in deficit. One of the priorities of all energy policies for the Third World, therefore, must be the improvement of the efficiency of stoves, hearths, etc., together with reafforestation.

The inadequate transport systems of most Third World countries constitute another major obstacle to development: we need only recall the importance of cheap means of transport during the industrial revolution to realize that this is a key problem: in this field an effort to improve traditional practices based on animal traction and to introduce more modern technologies is indispensable. More generally, energy policies based exclusively on traditional resources will not help the Third World to escape from an energy famine that not only bars any hope of development but threatens the very existence of the population.

Better use of solar energy is certainly indispensable; hydroelectricity, which is a renewable source but calls for the installation of an extremely costly electricity network is badly suited to the needs of what are, by and large, rural populations.

There remains fossil energy, above all oil and gas, much more convenient to use than coal. Most Third World countries have an oil potential that is not

being exploited or even explored at the present moment: many specialists(1) consider the exploration of potential gas and oil resources in the Third World the priority of priorities. They are doubtless correct, especially if the yield from these resources is invested in durable energy equipment: the carefully balanced use of oil and gas would, moreover, help to alleviate the energy burden that weights so heavily upon the inhabitants of the Third World.

These options presuppose true international co-operation - which is cruelly missing today - and they also come up against numerous economic and socio-political obstacles.

IV. ENERGY AND ENVIRONMENT

All human activities involve the use of energy: this fact entails a whole series of environmental effects at the point of mining or drilling no less than during transport right to the point of utilization. These overall effects on the environment (buildings, open spaces more or less artificially re-designed by man, living beings including man, scenery, the national heritage, ...) are either chronic (permanent or recurring with fair regularity, widespread or more rarely localized) or accidental (in which case they are generally localized at first even if they are later extended to wider areas).

Without making a full list of all the problems the use of significant quantities of energy poses for the environment, we can say a few things about the main types of energy used.

As far as coal is concerned, its exploitation has important scenic repercussions (the aesthetics of pitheads, tips of sterile material representing up to one-third of the tonnages extracted, scars left by open-cast mining, ...); at the health level, it is the cause of miners' silicosis (a grave pulmonary disease), and it has been responsible for many disasters (firedamp explosions). The combustion of coal involves the production of sulphur dioxide and its release into the atmosphere: this form of atmospheric pollution poses a threat to human health (chronic bronchitis), to the longevity of buildings and monuments (crumbling of limestone in particular) and to forests, rivers and lakes (acid rain).

The oil industry, too, is associated with a series of catastrophes: oil-well fires (some at sea), platform mishaps at sea, oil slicks (grave coastal pollution, but also chronic dumping of oil), refinery explosions. Some fuel oils also contain sulphur (up to 4 per cent by weight): their use releases sulphur dioxide into the atmosphere, just as happens with coal. The use of petrol in motorcars and in aeroplanes is responsible for another form of atmospheric pollution: the liberation of nitrogen oxides, of complex irritant derivates (PAN - peracetyl nitrate), of unburnt hydrocarbons, of carcinogenous substances (benzopyrenes), of additive residues (lead) ...

With gas, too, accidents may occur, though more rarely (risk of explosion during extraction, transportation or storage). The most common accidents are associated with domestic use and generally affect no more than a few people at a time (explosions in private houses, gas poisoning and asphyxiation). Natural

(1) Particularly P. Desprairies, 'La première des priorités: l'exploration pétrolière et gazière des pays du Tiers Monde'. Revue d'Energie (1983), pp. 654-660.

gas also contains sulphur products (SH_2, SO_2) with a risk of atmospheric pollution that can generally be averted by appropriate treatment.

To produce hydraulic energy we must build dams, usually on a gigantic scale. Their construction entails the destruction of whole areas (often densely populated and fertile valleys), regressive erosion of the slopes of the basin (with effects on neighbouring areas whose cumulative destruction eventually silts up the dam), the loss of fertile matter downstream (the case of Aswan where there were also sanitary problems of a special kind, namely bilharziosis). The periodic emptying of the dam to clear it of accumulated silt often leads to the large-scale destruction of fish. Accidental bursts, fortunately rare, have a lethal effect.

Arguments about the construction of nuclear power stations are chiefly centred round the potential risks: the supporters stress the fact that there have been very few if any deaths in nuclear power stations, the adversaries fear widespread radio-active pollution of the air and water, or thermal pollution of rivers, lakes and the sea and the risks associated with possible accidents (Harrisburg, United States). They insist that the potential effects on the population as a whole must first be evaluated (increased incidence of cancer: cf. the polemics about the Windscale reprocessing plant in the United Kingdom). They also stress that the production of plutonium, a by-product of certain nuclear processes, supplies the material for making atom bombs. Nuclear power stations have a limited life: these 'modern cathedrals' as some people call them, leave conspicuous scars on the landscape.

The 'aggressive' effects of gigantic developments on the environment can also manifest themselves with so-called soft energies: some solar power stations cover vast areas, enormous batteries of wind-driven generators can profoundly change the scenery.

The use of such vectors as electricty is not devoid of domestic risks, and of the risk of electrocution in particular.

On the planetary scale, numerous studies have shown a fairly significant transformation of the atmosphere, with possible long-term climatic effects, especially due to increases in the carbon dioxide level connected with the continuous combustion of fossil fuels (coal, oil and gas) since the beginning of the industrial era.

The picture we have drawn seems rather sombre and may arouse dreams of a return to a Garden of Eden blessed with a minimum use of energy. In reality, we can hope for no more than a medium-term energy policy minimizing the deleterious impact on the environment while maintaining a reasonable level of energy consumption.

PART TWO

ENERGY AS A THEME OF ENVIRONMENTAL EDUCATION

CHAPTER I: THE EDUCATIONAL METHODS AND THEIR APPLICATION

I. THE ESSENTIAL EDUCATIONAL APPROACH IN EE(1)

No matter what the chosen theme, environmental education demands the use of so-called active educational methods which run counter to the classic system of lectures in a classroom and of basing knowledge exclusively on a teacher's say so ... Environmental education methods are based on constant exchanges between the group made up of teacher and pupils, on the development of the pupil's autonomy, on the clearest possible definition of the objectives and on constant evaluations during and at the end of a particular project or activity. They involve a number of approaches some of which have been set out in another Unesco publication(2).

They can be briefly described as follows:

1. Guided environmental interpretation

Awareness of environmental problems and the consequent involvement of individuals cannot be fostered unless these problems are set clearly in the framework of people's lives. Hence it is advisable to start with guided environmental interpretation, a method that starts out with an analysis of the environment based on observations and surveys and then turns to various documentary 'sources' (publications, competent persons called 'human sources or resources' ...).

Often, there is a need to develop an activity 'transplanted' to places other than those in which the individual is involved in his daily life; in that case systematic experiments will always prove very profitable but must subsequently be applied in practical life if they are to provide a real motivation for action in the pupil's normal environment. In all cases, the interpretation of the data should help to establish what elements are at work in the genesis and operation of the observed structures and processes, and what the interrelations between these elements are. Beyond the descriptive aspect, the student will be led to a critical analysis of situations and phenomena (see below: Value analysis).

2. Discussion groups

This is a basic technique and should be applied in conjunction with all the others. Learning to exchange views, to be tolerant, developing better social relationships, ... are the essential aims of this form of education. It will also drive home the need for some organization of the discussion groups and of the discussions themselves as a measure of their real efficacy.

3. Value analysis

The fact that, in dealing with environmental problems, their causes, the search for solutions, the choice of alternatives, ... one is constantly forced to resort to value judgements (good-bad, beautiful-ugly) is something that should not be overlooked. On the contrary: an effort should be made to identify the values to which one constantly refers, sometimes non-explictly; it

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(1) EE = environmental education.

(2) Unesco, Division of Science, Technical and Vocational Education, Environmental Education Series 15, 'A problem-solving approach to environmental education', pp. 1-59, 1985.

would be quite wrong to ignore the clash of opinions and hence of different value choices; they should be aired in a climate of careful attention and tolerance. This point is essential for any real form of environmental education, because it reflects very clearly what happens in political and social life: if environmental education is to become a true form of civic education, value analysis must be an integral part of it.

4. Games and simulation

Although games and simulation involved 'artificial' situations, they facilitate the approaches we have mentioned: discussion, clarification of values, ... Even without resorting to games and simulation systematically, we can often use them to good advantage. Role-playing is traditionally based on asking the participants to portray certain well-defined persons (e.g. a local government officer, a farmer, a consumer with a given social status, ...) in the context of a particular problem, a well-defined real situation and clearly defined values. The accompanying discussions of the causes of an environmental problem and of the choice of solutions will provide an excellent means of clarifying values and will often offer a chance of determining appropriate activities in the field.

Simulation calls for a good description of the interacting elements and if possible for an approximate quantification of the interrelated effects. It should be possible to establish very simple (or more elaborate) models based on more or less complex foundations. However, one should be careful not to turn the results of an artificial game into 'images' of the future: they must be subjected to a rigorous critical analysis(1).

5. The experimental workshops

An experimental workshop is useful whenever there is a need to create objects with at least a demonstrative function. That is always the case when we try to communicate with others (other classes, parents, the community, ...) through:

newspapers;

posters or panels;

photographs, films;

audio-visual displays, ...

However, this type of communication with the outside world and the relative simplicity of the means used do not necessarily conjure up the name of workshop. A workshop involves the construction of working models or, better still, of lifesize prototypes intended for specific uses corresponding to real, identified needs. The object thus constructed is already one element of the solution of the problem.

6. The action-directed solution of problems

Devising or better still implementing concrete actions in the frame of environmental studies is an essential aim of environmental education and a means of arriving at a general evaluation of the action itself, the efficiency of the methods of analysis used and of the practical applications of the knowledge and skills acquired. It might be argued that written accounts are, in

(1) Unesco, Environmental Education Series No. 2, 'Guide on simulation and games for environmental education', pp. 1-101, 1983.

themselves, a kind of educational spur and an operational action. However, there is no action unless there is a project and unless that project is implemented to produce a tangible ordering, structuring, recovering, ... of objects, places, constructed sets, natural environments ...

In some cases, that operational action rests on prior educational, socio-economic, technical, ... studies or on a combination of these various aspects: in that case we speak of action-research.

7. The educational follow-up

The overall educational approach of environmental education involves an educational follow-up that progresses from the initiation of the activity, the definition or demonstration of the motives, a preliminary definition of the objectives ... to a short or medium-term evaluation, all involving constant checks of whether or not the action at each phase matches the objectives and the evaluation. This educational follow-up allows for possible changes of tack and hence for adaptations based on increasingly better understanding of problems and the maturation of the teacher-pupil group ... while maintaining a minimum organization to prevent loss of motivation and to ensure the achievement of concrete results for the gratification of the participants.

II. VARIOUS TYPES OF ACTIVITY: APPLICATIONS TO THE ENERGY THEME

The various educational approaches or techniques we have mentioned should be translated - most frequently in combination with one another - into activities by teacher-pupil groups, account being taken of the specific aspects of some of the themes under review, of local cases, of the field of application of the activities ...

When it comes to energy, considered a pluridisciplinary theme from the environmental education viewpoint, the possible activities are numerous, and it is rather difficult to classify them; the divisions we have nevertheless established do not therefore reflect very formal separations, especially not at the level of overall activity.

1. Analysis of, and reflection about, the environment with the help of documents

This type of activity crops up in environmental education projects from the initial phases, especially when it comes to the choice of a theme and/or an underlying study, and recurs throughout the course of the activity.

Over and above the analysis of the environment and the identification of problems in situ, reflection on specific points, essentially of a conceptual order, will often be found to be indispensable, albeit it cannot be considered an essential part of environmental education; a judicious choice of documents or texts will, in that case, facilitate discussions capable of illustrating certain concepts as clearly as possible. Here we shall merely give a few examples of this type of procedure.

(a) Analysis of economic statistics

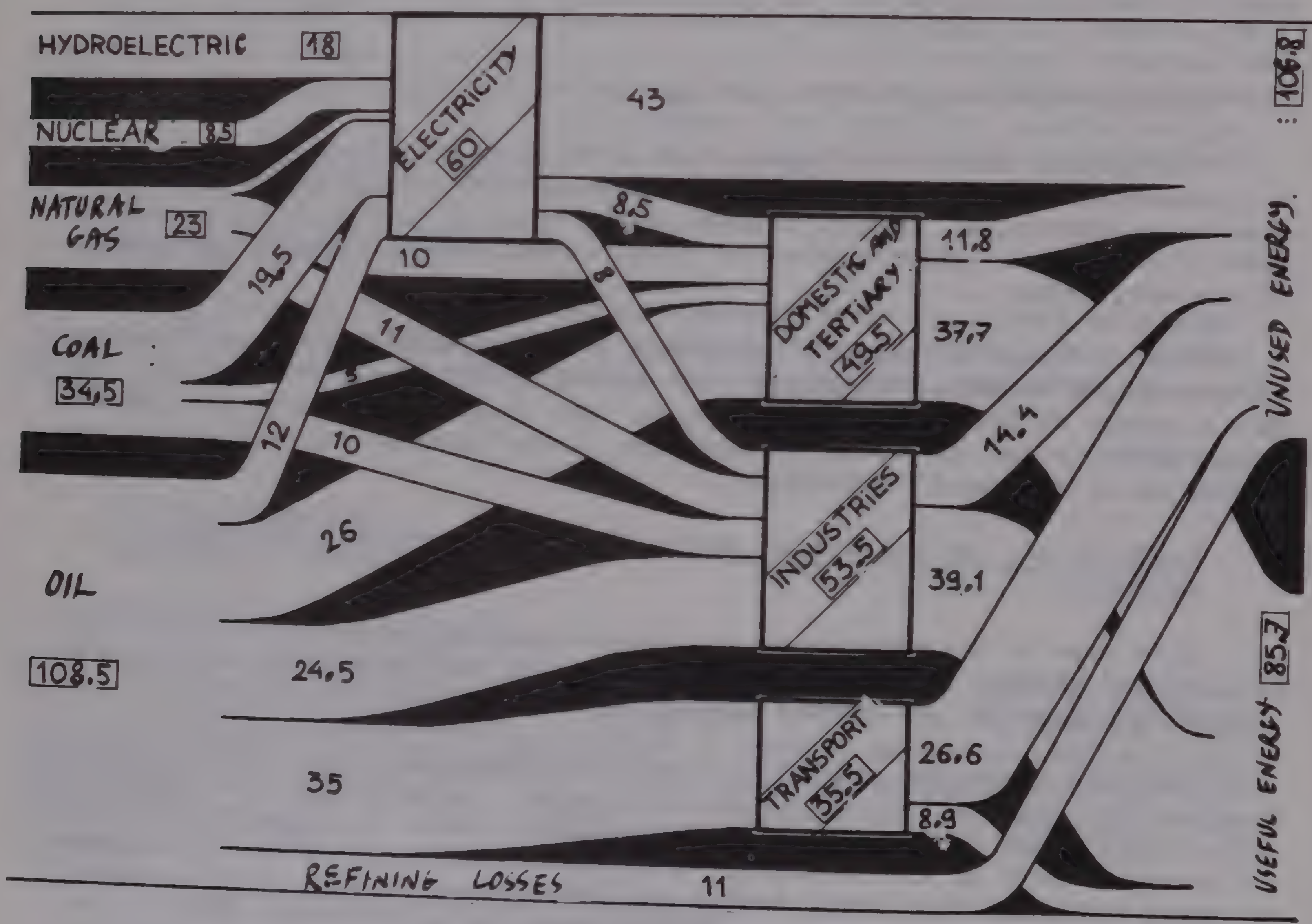
Reserved for more advanced classes familiar with problems of human geography and economics, this type of analysis rests on the study of statistics, most of them drawn up on a national scale but sometimes also on a regional basis.

(1) The mere examination of the distribution of consumption levels sector by sector, of the choice of these sectors, ... can lead to interesting reflections.

(2) It is possible to obtain an evaluation of the various types of direct and indirect consumption in every sector by consulting a TIE (Table of Industrial Exchanges).

(3) Some figures also provide a balanced view of the operation of a national energy system, showing how the sources are linked to the various sectors and what the losses are. The search for the origins of these losses is an exercise that provides a concrete glimpse, on the one hand, of the consequences of the inescapable constraints of the laws of thermodynamics, and on the other hand, of the methods of controlling energy through the operation of the economy.

In this framework, some schemes merit more detailed examination. The energy flow of a country, from the sources to the point of consumption, is often presented in the following form:



ENERGY FLOW IN AN INDUSTRIALIZED COUNTRY

(France in 1979; Unit: one million tonnes of oil equivalent)

Such concepts as lost energy (entropy, constraints imposed by the laws of thermodynamics) and of useful energy are easily introduced and discussed with the help of such documents; in addition, they bring out the special characteristics of the use of energy by the countries in question.

(b) The analysis of texts

As our first example, we shall quote a passage from the writing of the economist, N. Georgescu-Roegen(1), which can serve as an excellent basis of discussion leading to an elucidation of the concepts of accessible and usable energy.

'Accessible energy and accessible matter

As we saw, the distinction between usable and non-usable energy (generalized by the distinction between low and high entropy) was introduced in thermodynamics to account for the fact that man can only make use of a particular energy state. However, this distinction does not mean that man can use all forms of usable energy no matter where they are found or in what form they appear. If the usable energy is to be of value to man, it must also be accessible. Solar energy and its subsidiary products are accessible to us with practically no effort, without additional consumption of usable energy. In all other cases, we have to invest labour and raw materials to draw on reserves of usable energy. Even if we should one day be able to settle on Mars and discover reserves of gas there, the usable energy would not be accessible to us if, in order to extract one cubic metre of the gas, we should have to invest more energy than the equivalent of one cubic metre of gas on earth. There are bituminous schists from which we can only extract a ton of petroleum by using more than a ton of petroleum to do so. In such deposits, the petroleum would still represent usable energy, but not accessible energy. We have been told ad nauseam that the real reserves of fossil fuels are certainly greater than any that are known or have been estimated, but it equally certain that a substantial part of these reserves does not constitute accessible energy.

The distinction with which we are concerned here involves energy yields, not economic returns. An economic return implies an energy yield, but the reverse is not true. The use of gas, for instance, is more profitable in energy terms than that of electricity but, in a good many cases, electricity comes more cheaply.

Thus, although it is possible to produce gas from coal it is cheaper to extract it from natural gas deposits. If the natural gas resources were to become exhausted before coal, one would certainly have to resort to a method that, at present, is not economically profitable. This idea ought to be borne in mind in all discussions about the future uses of solar radiation.

Nevertheless, economists argue that resources should be measured in economic rather than in physical terms. This attitude reflects one of their most obstinate myths (they are not its only victims) that the price mechanism can mitigate all shortages in land, energy or material. That myth will be examined below but, for the moment, let us merely stress that in the long run, the return must be expressed in energy terms, which involves an assessment of accessibility. True, the real yield at any one

(1) In N. Georgescu-Roegen, 1979: Demain la décroissance, Entropie-Ecologie-Economie, pp. 52-54, Editions Favre, Paris and Lausanne.

For simplicity's sake, we may put it that adaptation to climatic conditions is achieved by making allowances for:

the wind (protection from the wind or using the wind for cooling purposes);

temperature (insulation, storage of heat, cooling, search for a good facing position to caputre the heat of the sun);

solar radiation (light and heat);

rain or snow.

Properly designed buildings are one of the oldest means of making good use of energy (even if that fact is not always conscious or expressed). Protection from the elements and the husbanding of energy resources join forces in this more or less empirical approach.

Many educational activities can be designed round the analysis of this feature of urbanism and architecture:

the lie of villages in the landscape;

the type of housing (detached, semi-detached, ...), size of roads, vegetation;

the type and colour of the building material, the size and position of doors and windows;

the plan and organization of house;

the demands on the domestic energy budget, ...

Beyond certain well-publicized cases, which have a spectacular character but do not necessarily occur in the child's environment, the teacher must try to use an analytic technique rooted in the child's daily surroundings which are often humdrum villages apparently devoid of any interest. The child must be led to make genuine discoveries in his description of the bioclimatic approach used but not always apparent, or in his critical study of its absence. Nor should the formulation of reasonable wishes, the enunciation of proposals, the elaboration of construction plans be neglected in the overall analysis (see facing figure).

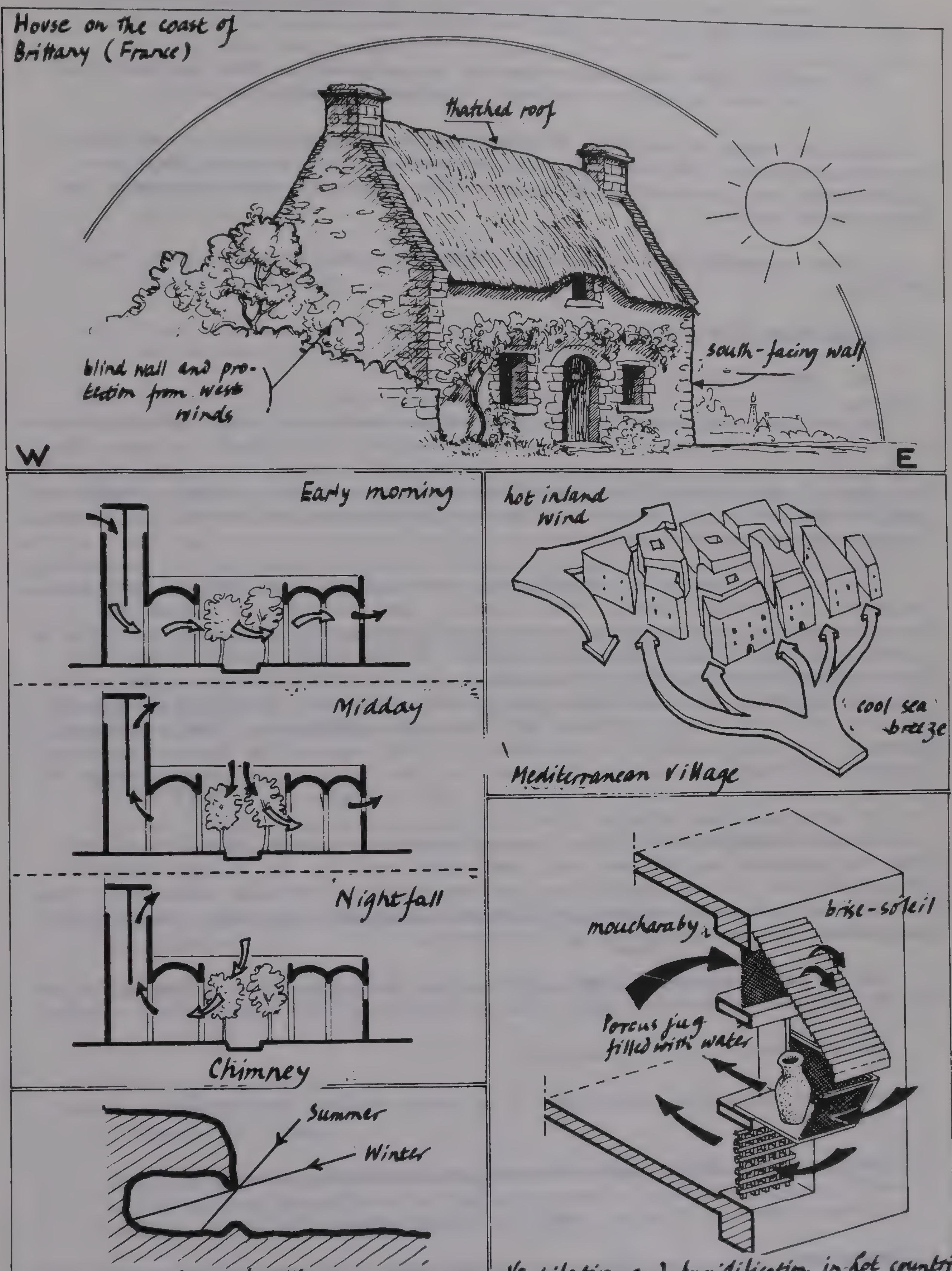
(c) <u>Drawing up energy balances by eco-energy analysis</u>

This type of analysis is still in its infancy, but should not be ignored by educationists; indeed encouraging attempts in that direction have already been made. However, the analysis demands a relatively late school level (end of secondary education), especially if the teacher wishes to introduce a quantitative dimension.

This method makes it possible to work on a local level starting from data gathered by inquiries or questionnaires and is therefore fully in line with the environmental education approach. Moreover, it also facilitates the drawing up of an energy balance for the country as a whole from the relevant economic statistics. In practice, eco-energy analysis (EEA) forces us to:

(1) define and delimit the system under review;

(2) collect the necessary data;



(after Archibio 1979)

(3) treat these data with a view to obtaining a (mathematical) expression of the energy involved;

(4) analyse the results, and possibly use them to draw up proposals (improved production methods, development plans).

For the rest, since what is involved is an environmental education activity, attempts must be made to communicate its results (dialogues, exhibitions, ...) to individuals and to the community concerned with the system under review.

In the appendix, the reader will find practical hints on that type of activity.

3. Activities of a chiefly manual nature

(a) General approach

In environmental education it often seems useful and even indispensable to involve the participants in a concrete activity. Practical set-ups, the construction of a piece of apparatus or simply of a model of it, all go with this type of approach and have the added advantage, thanks to their manual and experimental nature, of offsetting the so-often disparaged academicism of traditional educational activities.

A very large number of experimental set-ups are described in physics textbooks of various levels. The majority are intended to establish, demonstrate or illustrate basic concepts and fundamental laws and to arrive at quantifiable expressions and measurements. It is plain that a formal and abrupt introduction to that type of set-up is not likely to arouse the pupils' interest. However, if a concrete problem and analytical difficulty lead the pupils to it, then their attitude will be quite different. Some textbooks, moreover, try most laudably to establish a clear connection between physical concepts and everyday reality. The need for the relevant experiments must be felt spontaneously; it would be futile to try to impose it on pupils.

In environmental education, the choice of the energy theme thus often leads to practical activities, and that might well be one of the teacher's main objectives. If such activities are the result of serious reflection, they will be preceded by an approach of the experimental type, with tests, prior measurements and an evaluation of the results.

Let us take the case of the construction of a flat-plane solar collector for the purposes of heating water. The principles of its construction involve:

the greenhouse effect (glazing);

the heat-absorbing properties of a given surface (preferably a black surface);

the transport of the captured heat (usually by air or water);

storage (various liquids, pebbles, walls, etc. ...).

Even when these principles are granted from the outset after observation of a ready-made collector or of its design, it is a good idea to verify them, if only to choose the most effective method of construction and the best materials. To that end, the following questions will have to be answered:

(1) How does the greenhouse effect manifest itself? To determine that, temperature measurements must be made, the captured heat must be confined in a space behind the glass; there must be experiments with single and double glazing and with other materials (plexiglass, plastic foil, bubble layers, ...).

(2) How is the heat to be 'transported'? Are there losses? (Temperature measurements, experiments with tubes or pipes of varying diameter, examining the problem of insulation, choosing the best insulator, ...).

(3) How should the receptor surface be selected? (Material, colour, conduction by metals, ...).

(4) Where and how should the heat be stored? (Choice of location; storage medium, storage chamber, insulation, ...).

The need for making comparative tests and for taking temperature measurements (thermometers, thermometric probes) seems self-evident in this case.

The measurement problem also arises when we want to gauge the effect of an energy-saving device (insulation, for instance). Similarly, in the energy calculations for a particular installation, or to determine the costs of running a house, no proper formulae can be obtained without adequate mathematical expressions of the basic concepts: energy, power, work, transformation of energy, degradation of energy, efficiency, ...

(b) An example of an activity centred on the solar energy theme

We shall now describe a project devised by pupils in the College J. Valeri in Nice, the actual work being done by a team of teachers at the CEMEA (Active Methods Training Centre).

'Study of the sun

- motion: study, use and/or construction of simple instruments to elucidate the underlying phenomena: gnomon, sundial, heliolabe, theodolite, sun compass, ...

- solar phenomena: sunspots, granulation, limb darkening (study, photographs), ...

- radiation: solar spectrum, solar constant, helioscope, ...

Solar energy

Collecting the energy:

- influence of colour;

- study of greenhouse effect (single, double and triple glazing; comparison of glazing materials; distance between two glazing layers; distance between glass and absorber);

- study of concentration effect (position-seeking mirrors; semi-cylinder, cone, paraboloid, sphere; position of absorber with respect to reflector);

- importance of insulation: test of various materials;

- comparative study of the thermal properties of materials;

- study of the importance of direction of the collector;

- importance of evaporation in a heat exchanger and in a swimming pool;

- study of photo-voltaic cells;

- calculation of the power of various school instruments.

Heat exchange and storage problem:

- by contact;

- by circulation of a liquid or gas; problem of thermophons.

Problem of siting houses: prior study of roof constructions designed to avoid the sun reaching the south-facing wall in the Southern Hemisphere.

Design and use of experimental and practical materials

- diaporama; experimental solar collector;

- hot-air collector for use in the classroom; solar cigarette lighter;

- solar grill;

- study to reduce the heating of air in tents;

- solar collector for a holiday village and a public hot water fountain;

- solar shower; solar cannon;

- model solar merry-go-round;

- model houses, ...

- as projects: study of water heating in a large pool (the swimming pool of a holiday centre).

Launching a (reduced model) solar energy hot-air balloon.'

4. The search for solutions to environmental problems

The main aim of environmental education is to avoid environmental problems or, where they already exist, to help surmount them. This can be a long-term project for citizens whose awareness has been stimulated by environmental education, especially during their school years. Every environmental education activity or exercise should culminate in some tangible achievement. This may take the form of producing a material that will work effectively and will be of practical use, or of organizing some activity benefiting the community and involving the largest possible number of people in a process that involves greater familiarity with one's own environment.

It is advisable to underline the significance of a given exercise by defining its impact on people's individual and collective lives ... The range

of projects can easily extend from the individual (at home, at school, ...) to local communities of a fairly small size (village, district, ...). Beyond that point, however, it will be necessary to contact local authorities and special associations. All the exercises have an educational character inasmuch as they involve a large number of people: the results must be made public and a wider circle must be induced by example to engage in similar operations of the same kind.

As far as energy is concerned, two lines of approach are possible. First of all, in considering the effects of some forms of energy on the environment and on local, regional and national development, people will be encouraged to put forward solutions that reduce or eliminate the most undesirable of these effects. Moreover, if attention is focused on the husbanding of resources, energy savings will become the paramount consideration. To make the most of this subject, the reader should stress that energy savings can apply to direct consumption (energy vectors: oil, gas, electricity, ...) no less than to indirect savings (objects, buildings, various products).

Energy savings often result from simple changes in habits and attitude (e.g. switching off lights when leaving a room, making full use of the gears when driving, ...), from the introduction of what are sometimes quite elementary devices (draught excluders, stoves for open-air cooking, ...), or from better control and distribution systems (heat regulation in blocks of flats).

All recycling operations (metals, glass, paper, ...) and all maintenance and repair work (the fight against wear and tear and waste) are indirect forms of energy saving.

Similarly, the search for alternative sources of energy, differing from current methods of production and consumption - whether they be entirely novel or based on a return to old methods that have fallen into desuetude - can sometimes contribute to energy saving as well as to changes in lifestyle.

CHAPTER II: DESCRIPTION OF THE MODULE AND OF ITS USES

The structure of the module

When used to further the general objectives of environmental education, a module is meant to help students and teachers:

to take an objective view of the preoccupations and values on which the rational management of resources is, or should be based;

to engage in practical activities reflecting their level of environmental awareness and desire to shoulder some responsibility for the management of resources.

The module presented here, as part of the general theme of energy is intended, in particular, for school pupils in two age-groups (roughly the first and second years of secondary school) and is based on the fact that, as children grow older, they can be made to:

advance from subjects based mainly on an appeal to perception to more abstract subjects;

pay greater attention to quantitative aspects and to more complex interrelationships;

extend, if necessary, the field of the investigation (school, district, town, region, country, world);

put forward remedial suggestions or more credible alternatives based on technological information.

The module is divided into eight sections, each with a subsidiary theme of its own:

energy; definitions and forms;

units of energy and power: the concept of efficiency;

history of the use of energy;

energy chains and the transport of energy;

energy production;

the use of energy in the main sectors;

energy economics and energy saving.

Each section is made up of a descriptive passage (presentation text) and one or more worksheets.

The presentation text has several functions:

(1) it allows teachers and pupils to acquire or revise conceptual or cognitive notions rapidly;

(2) it provides a basis for discussion prior to the use of the worksheets; such texts are not sacrosanct: progress can also be made by subjecting them to valid criticism;

(3) it supplies a framework for wider research into the subject under discussion.

For further documentary material the reader is referred to the various sources acknowledged in Part One and in the appendices of the present publication. Further bibliographic material should be chosen and presented with appropriate comments to their pupils.

The worksheets contain suggestions that must be modified to suit the prevailing conditions, the means at the pupil's disposal, their abilities, and the kind of environment in which they live.

Major modifications will have to be made to suit any of the four possible and very different types of environment, viz.:

heavily industrialized, predominantly urban societies;

heavily industrialized societies in which rural areas are still of some importance;

moderately industrialized societies with large urban areas;

moderately industrialized societies with predominantly rural areas.

All the worksheets are based on an identical layout, presenting

The aims and objectives

The student's level:

- Level I corresponds roughly to the early stages of secondary school education (some exercises, if simplified enough and if based on single choices can even be used by children at the end of their primary education);

- Level II is reserved for the latter stages of secondary school education, but can also be used for the training of teachers in multidisciplinary teams.

When both levels are given, the teaching team should encourage such lines of investigation as accord best with their students' level.

The subjects: Not all the subjects listed under this heading need necessarily be taught for a teaching team to function effectively.

The material: This should be determined at the start of any exercise but can be amended as the need arises.

Exercises: These are based on questions, suggestions, documentary searches ...

Projects: These are aimed at practical actions involving the solution of environmental problems; the ideal is to arrive at either the implementation of a practical plan (e.g. building a machine with a precise

function) or organizing an activity, the results of which will be obvious (e.g. reducing the energy consumption of a piece of equipment); the minimum requirement is that others in the school community, and above all in the outside world, should be informed of the results in such a way as to increase their environmental awareness, which by itself constitutes an act of environmental education.

All this has a twofold function:

- first, to take stock of the results of the activity or exercise, if only by means of a simple dicussion and a tabulation of the conclusions;

- second, to stress the relevance of these conclusions to the outside world, that is, to the community concerned with the problem under review. Incidentally, this may necessitate extending the original time schedule, if, say, additional research or practical work may turn out to be needed. For that reason, the time needed to complete the various exercises is not stipulated in the worksheets.

<u>Educational aids</u>

The educational activities suggested vary depending on the subject; for the most part, they are based on the use of such active educational methods (see Chapter I of Part Two) as:

(a) <u>Observation of the surroundings</u>: students' observation of their surroundings (at home, in the street, in their normal environment, ...) provide the basis of the necessary information and as such give rise to reflection; by asking pointed questions moreover, the teacher can encourage greater accuracy and depth, and sometimes steer students towards more advanced inquiries in a particular field or generally help to extend their documentary and conceptual tools. The inquiries frequently lead to meetings and interviews with concerned people (local inhabitants, officials, maintenance workers, etc.). The report on the results of these inquiries and observations must be compiled with special care because they are a major element in the armoury of the pupil-teacher group.

(b) <u>Documentary research</u>: the study of documents takes various forms and serves various ends. Illustrations (photographs, drawings) clipped from magazines for example, can be used to create a series of images:

as aids to discussions;

for use in game playing (e.g. cards);

for presenting the results.

Texts and statistical data not only contribute to understanding but also stimulate thought and lead students on to other bibliographic sources.

Big companies, private or semi-public bodies and ministries concerned with energy problems often publish information intended for the public, and sometimes specially written for schoolchildren.

(c) <u>Games</u>: there are some carefully designed aids, mainly intended for the training of senior staff and based on the possibility of <u>simulating</u>, say, economic situations at company level. Many of these aids are devoted to the

control of resources (particularly energy). Their level of sophistication is beyond the capacities of secondary schoolchildren. Simpler games involving, say, matching cards or a type of snakes-and-ladders board with squares representing situations and ideas ... can also be devised either by teachers before, or by teachers and pupils together during, the exercise. Some games sold in toy-shops, etc. can also be used: the pupils are encouraged to analyse their objectives and the way in which these can be attained.

Role-playing games play an important part in this area: pupils are asked to impersonate someone who, in a given situation, plays a decision-making role (e.g. an administrative official) or helps to shape public opinion (e.g. an activist in some pressure group) ... All the actors then take part in a debate, which helps them to appreciate the values defended, and the constraints, and also shows them how to define objectives and make the relevant choices ... Such role-playing games can be a preparation for interviews or for attending public debates: they also foster tolerance and lead to the formation and expression of considered value judgements.

(d) Inquiries and interviews: their aim might be the analysis of various types of public attitude (or of the attitude of a particular section of the public) to a given problem. However, their most important objective is to identify the structures and, within them, the individuals, that allows society to make choices, to take what steps it deems necessary at the technical and human level. On the information level, contact with experts and technicians will often be essential to anyone anxious to discover the relevant constraints. A variety of interviews together with a careful analysis of the responses elicited guarantees a more objective approach and will lead to more rational and measured appreciations of the situation. The most important point is to determine how individuals in a given community feel about, and regard their place in, the environment.

Interviews with experts are also a source of information not only on technical and economic problems but also on the constraints to be taken into consideration when making choices and on the type of value brought to bear consciously of unconsciously on decisions. However, the need for objectivity, which is often obscured by too partial approaches, should always be borne in mind.

(e) Concrete environmental action: action on one's environment is the best possible contribution to the problem-solving educational approach: it should therefore be given preference. Practical activities call for organization and perseverance. Choices will range over a rather extensive spectrum, from, say, the elaboration of a project for submission to responsible bodies to the actual performance of certain tasks (e.g. collecting materials for recycling, ...). Activities or exercises intended to increase group awareness also deserve close attention as they can encourage actions by officials and other adults.

Some guidelines for the use of the module

1. As far as its content is concerned, the module has been designed for highly flexible use. In effect, the canvas presented here is vast and anyone trying to make use of it all will find it very difficult. In practice, the teaching team will proceed from a concrete problem related to energy (e.g. domestic energy consumption; see Section VII) and go on to identify among the essential facts and concepts presented in other

sections those which seem a priori the most important for the analyses and understanding of the chosen topic; teachers will have to use several other worksheets, either in part or as a whole.

2. If the teaching team has enough time and if it is anxious to view its own procedure in context, it can gauge the pupils' progress from the sequence of stages presented in the table on the next page.

3. As for the evaluation of the impact of the module on the pupils' knowledge, the teaching team must devise tests which can take several forms:

   open questionnaires for individual or collective use; such questionnaires can even encourage the writing of short texts;

   closed questionnaires, e.g. of the multiple choice or true-or-false type for individual use.

   Though these evaluation techniques are meant as tests of progress, they can also serve as preliminary tests of the pupils' initial grasp. An overall evaluation, for the teaching team, will be based on collective self-assessment, which will essentially take the form of open discussions and exchanges of views. At the pupil level, it will be based on designing (or better still implementing) collective projects centred on environmental problems to which the pupils can apply their recently acquired conceptual, cognitive, methodological and practical abilities. As an example, this chapter ends with the evaluation sheet suggested in the 'Educational Model on Conservation and Management of Natural Resources' (No. 3, Unesco, 1985).

4. The experimental nature of our module must be stressed: teachers should treat the contents and the methods proposed in a critical fashion and make any possible changes demanded by environmental, economic and cultural conditions.

(i) Identification of problems, description of facts and of processes in their interrelationships.

↓

(ii) Exposition of the main concepts; list of the main items of basic knowledge.

↓

(iii) Clarification of values involved in the problems under review.
Analysis of attitudes to these values.

↓

(iv) Definition of educational objectives.

↓

(v) Suggestions for educational activities.
Practical exercises.

↓

(vi) Making contact with people outside the school system to publicize the procedure used and its results.

↓

(vii) Evaluation of the exercises and the educational procedure.

STAGES IN THE PROGRESS OF AN EXERCISE
IN ENVIRONMENTAL EDUCATION

Sample evaluation sheet

Questions

1. Physicists distingish different forms of energy which can be transformed one into another. What are these forms?

2. What are the different forms in which energy is supplied to consumers?

3. What are the basic resources from which energy is obtained?

4. How can renewable sources of energy be distinguished from non-renewable sources? Give some examples.

5. What forms of energy are used in transport today? In former times?

6. In your country, what sectors are the biggest consumers of energy?

7. What is the total energy consumption in your country? What is the average consumption per head of the population?

8. What, approximately, is your direct personal consumption? Indirect consumption? Add the two together and compare with the consumption per head of the population.

Multiple choice

1. Fossil fuels are ... forms of energy:

   (a) poor; (b) concentrated; (c) renewable; (d) inexhaustible.

2. Pollution (industrial, domestic and from the consumption of energy by vehicles) ... a necessary evil:

   (a) is; (b) is not; (c) is perhaps; (d) neither (a), (b) nor (c).

3. Our energy needs are ...:

   (a) the same for everyone; (b) always the same; (c) an inherent factor; (d) largely artificial.

4. The new energies can be produced ...:

   (a) only by creating a lot of pollution; (b) without creating pollution (or creating very little); (c) neither (a) nor (b).

5. Wind is a form of solar energy resulting from ...:

   (a) the motion of the sea; (b) differences of temperature in the air; (c) the gravitational pull of the moon.

6. Solar energy must be ... to serve as an alternative source of energy:

   (a) cooled; (b) captured and if possible concentrated; (c) heated.

7. The forms of energy to be found in the ocean are ...:

   (a) the wind; (b) shellfish and algae; (c) the tides; (d) hydro-electric energy and electricity.

True-or-false

1. Energy is essential for communications and transport.
2. The production of energy always consumes non-renewable resources.
3. Our society cannot do without cars.
4. Certain societies use neither fertilizers nor machines in their agriculture.
5. The use of fertilizers and machines does not consume energy.
6. Many kinds of waste matter can be used for producing energy.
7. Recycling metals is not a way of saving energy.
8. It is possible for motor vehicles to use less energy.
9. Goods cost more to transport by rail than by road.
10. Energy cannot be produced without causing a lot of pollution.
11. Natural renewable energy resources, such as firewood, are only renewable if their use is planned in a rational manner.
12. Economic growth and the demand for energy are at present inextricably linked.
13. The energy contained in uranium is in an even more concentrated form than that contained in fossil fuels.
14. Uranium is an inexhaustible resource.

CHAPTER III: ENERGY-THEME MODULE

SUMMARY OF CONTENTS

Section	Worksheets	Level
I. Energy: definition and forms	(1) Energy: use of the word, definitions and forms	I and II
II. Units of energy and power: the concept of efficiency	(2) Units of energy and power: efficiency rates	II
III. The history of the use of energy	(3) The history of the use of energy	I and II
IV. Energy chains and the transport of energy	(4) Energy chains and the transport of energy	I and II
V. Energy sources and resources	(5) The energy of the biomass (6) New energies other than the biomass (7) Nuclear energy: hopes and fears	I and II I and II II
VI. The production of energy	(8) The production of energy	II
VII. The consumption of energy	(9) Energy in the home (10) Energy outside the home: building and industry (11) Energy and agriculture (12) Energy in transport	I and II I and II I and II I and II
VIII. Energy economics and energy savings	(13) Energy economics and energy savings	II

SECTION I: ENERGY: DEFINITIONS AND FORMS

PRESENTATION TEXT

Energy: use of the word

The word energy is widely used in everyday life and no one, regardless of education, profession or status, hesitates to use it. However, many people would be exceedingly embarrassed were they asked for a precise definition of energy - and few of those who could provide one, are likely to satisfy a professor of physics.

This fact alone demonstrates several things, namely:

(1) that energy is part and parcel of our daily life;

(2) that the public is more or less aware of its existence;

(3) that a word can be used meaningfully even if its definition and the more or less abstract notion it represents are not fully understood.

In search of a definition

A dictionary will quickly send us from the word 'energy' to the word 'work' and will often mention various forms of energy. How many difficulties and problems are raised by even this small excursion into the field of energy! The reason is that the word 'energy' covers an abstraction, a concept hard to come to grips with, even though all of us are so familiar with the effects of energy and the uses to which we put it. To begin with, we shall be using two classical definitions, the first being found in most dictionaries:

Energy is the ability to do work

Unfortunately, this simple definition is inadequate. Thus we know of many transformations that involve energy yet do not require us to make the least reference to the concept of work. When we burn a lump of coal or light up our rooms with the help of a light bulb or candle, there is indeed a transformation of energy but no work. For that reason, it is advisable to use an alternative definition, one that is more general and also considerably more abstract:

Energy is what must be supplied or surrendered to a material system in order to transform it

The various types of energy

No matter which of these two definitions we adopt, it is obvious that the term 'energy' refers to a large number of phenomena that vary considerably in type. Thus solar radiation supplies energy because it heats the oceans, evaporates water, moves the clouds. The water recovered in the form of rain and collected in rivers can do work, for instance impelling turbines to produce electricity ... To move about, we can rely on our own muscular energy (walking, cycling), on that of a horse (animal traction) or again on the energy delivered by the combustion of petrol in the engine of a car ...

The idea that energy manifests itself in different forms is therefore familiar to us. Among the most common forms, we distinguish:

Radiant energy: this is the only form of energy that needs no material support; it is propagated in a vacuum with a velocity close to 300,000 km/s; light is the best known example, sunlight being the most important for us.

Chemical energy, by contrast, is intimately bound up with the structure of matter; in particular it maintains the bonds between atoms in molecules, that is, between the 'bricks' of which all objects and living beings are made.

Mechanical energy does not depend on the composition of matter or on the nature of the constituent 'bricks', but on the mass of an object and on its position and displacement. When that mass is at rest and stored at an elevated position, we say that it has potential energy (e.g. the energy of water held back by a dam; an object suspended from a string, ...); when, by contrast, an object is in motion, it is said to have kinetic energy (e.g. moving vehicles and objects: a motor car or a flying stone).

Thermal energy is best known under the familiar name of 'heat'. It corresponds to the irregular movements of the atoms or molecules of which all material objects are made.

Electrical energy appears when electrically charged particles (such as electrons) are concentrated in a given region of space. A case in point is an electric current.

Any of these forms of energy can be transformed into any other.

It was in 1842 that a German physicist, J.R. von Mayer, stated the first principle of the equivalence of two very common forms of energy, namely heat and work. That principle was subsequently extended to all forms of energy. It is helpful to represent the transformations of the various forms of energy by means of a diagram(1) from which it can be seen that the five forms of energy described above, can be converted in 20 ways.

(1) See Appendix I.

WORKSHEET: Energy: use of the word, definitions and forms (Worksheet 1)

Aims and objectives:

To make it clear that, regardless of any formal definition (often abstract or vague), energy is omnipresent in our lives and activities.

To show that the classical method of identifying essential forms of energy is a first step in driving home the importance of energy.

Levels: I and II

Subjects: English (French), general studies, science, art.

Materials:

Dictionaries, encyclopaedias, popular books.

Magazines, newspapers, advertisements.

Pamphlets issued by energy-producing boards and companies.

Exercises:

(1) Look for the word 'energy' in newspapers, reviews, advertisements and other publicity material.

(2) Explain its meaning in the passages in which it occurs.

(3) Look in the same texts for possible connections between energy, force, work, matter. Note the most common associations with other words. Examples: energy crisis, energy savings, energy sources, energy resources ...

(4) Look up articles in an encyclopaedia or chapters in books on energy. Compare the definitions; write down the main keywords common to all your sources.

(5) What forms of energy can be identified in the propulsion of a motorcar?

(6) Look for a common example of each of the 20 ways of transforming the five main forms of energy. What are the most common machines or devices used in these transformations?

(7) How many ways of transforming energy would there be if we added a sixth form of energy to our diagram?

(8) Do you know any forms of energy other than those shown on the diagram? What are they?

(9) From the list of the different forms of energy write down all the possible pairs and then find the best technical means of changing one term of the pair into the other and *vice versa*.

(10) Design a large fresco representing all these transformations.

Projects:

Prepare a small exhibition for your parents or neighbours on the themes 'What is energy?', 'Energy and ourselves'.

SECTION II: UNITS OF ENERGY AND POWER: EFFICIENCY

PRESENTATION TEXT

The 'jungle' of units

A great many units are used in the measurement of energy and it is often difficult to find one's way in the resulting 'jungle' of symbols. If we used all these units jointly the result would be a kind of masked ball at which the various masks nevertheless hid the same reality. Thus we would successively watch the entry of the calorie, the kilowatt hour, the joule, the therm, the BTU (British Thermal Unit), all multiplied or subdivided with the help of prefixes indicating greater or lesser quantities, e.g. kilo-, mega-, giga-, tera-, centi-, milli-, giving kilocalories, megajoules, terawatt hours, ...

Particular caution must be used with intruders that are not units of energy but units of power. The most common of these is the watt with its multiples: kilowatts, megawatts, gigawatts, terawatts. This abundance of units and the consequent risk of confusion between them may seem daunting. Now there would be a relatively simple way out, namely the adoption of an international system of energy units based on the joule. However, in everyday life, when people talk of heat or the energy content of foodstuffs, they prefer to use the calorie and its multiples; in electricity the most common unit is the kilowatt hour; and when people refer to the energy consumption associated with heating, they usually think in therms.

The official unit - and the one everybody should use - is the joule. We shall here define it in terms of another unit, the calorie. The calorie is the quantity of heat required to raise the temperature of 1 g of water from 14.5°C to 15.5°C at normal atmospheric pressure. The relationship between the joule and the calorie is defined as follows:

$$\boxed{1 \text{ calorie} = 4.18 \text{ joules}}$$

Because the joule and the calorie are too small to be used in everyday life, it is customary to prefix them with:

$$1 \text{ kilo} = 1{,}000 = 10^3$$

$$1 \text{ mega} = 1{,}000{,}000 = 10^6$$

$$1 \text{ giga} = 1{,}000{,}000{,}000 = 10^9$$

$$1 \text{ tera} = 1{,}000{,}000{,}000{,}000 = 10^{12}$$

These units are not, however, convenient for people working in the coal and petrol industries, who prefer to use tonnes of coal or oil equivalent: i.e. the energy contained in a metric ton of coal or petroleum. People in the oil industry also use barrels: one barrel is equal to 159 litres. In view of the average density of hydrocarbons, it is usual to adopt the equation: 1 tonne = 7.33 barrels.

The electrical industry, for its part, likes to work in watt hours. Here it is important to avoid the trap of confusing two quite distinct concepts, namely power and energy. Power is the rate of doing work, i.e. it expresses a flow of energy and is measured in watts.

> One watt represents a flow of energy of one joule for one second

One kilowatt hour therefore corresponds to an expenditure of energy of 1,000 watts for one hour.

Watt hours can obviously be preceded by all the prefixes we have mentioned: kilo, mega, etc.

<u>The laws of energy transformation</u>

We know that energy can be changed from one form into another, but what precise laws govern such transformations?

The first law is particularly simple:

> In all transformations, the initial energy present in one form is conserved in all other forms.

This law, known as the first law of thermodynamics, simply concerns the amount of energy conserved. It can also be expressed by saying that <u>energy can neither be created nor destroyed</u>.

Let us take the case of a tonne of coal. If it is burned in a power station, all the energy contained in the coal will be conserved after combustion, though in other forms: heat released by the boiler, motion of the turbine, electricity at the end of the alternator. One could sum up this process by the following formula:

Chemical energy of coal	=	Mechanical energy	+	Thermal energy	+	Electrical energy

The second principle of thermodynamics concerns the quality of the energy. It can be expressed as follows:

> In a system that cannot exchange energy with the exterior - physicists call it an isolated system - the quality of the energy tends to become degraded.

What do we mean by degradation? We know how easily all non-thermal forms of energy can be transformed into heat - even when nothing could suit us less. Muscles and engines heat up while they produce mechanical energy; light bulbs heat up at the same time that they give off light. The heat produced by the muscle, engine, light bulb is most often unusable, if not useless. It simply escapes into the air, ...

The concept of efficiency

While attempts are made to keep these losses to a minimum, it is almost impossible to eliminate them altogether. This was first demonstrated by the physicist Sadi Carnot who showed that there was an absolute limit to the transformation of heat into work. He expressed that limit by saying that no machine can transform heat completely into work. Carnot even calculated the limit:

> In an ideal heat engine, the fraction of the thermal energy that can be transformed into work cannot exceed the limit $R = 1 - \frac{Tc}{Th}$.

where T_c is the temperature of the condenser (cold source) and T_h the temperature of the steam (hot source). The temperatures T_c and T_h are measures on the Kelvin scale (a temperature t expressed in degrees Celsius becomes $T = t + 273$ on the Kelvin scale).

Carnot's formula is a precise expression of the difference we observe in everyday life between heat and other forms of energy: the transformation of the other forms into heat is always possible, but the inverse transformations can only be partial and are sometimes impossible. It is for this reason that heat is considered a degraded form of energy.

WORKSHEET: Units of energy and power; efficiency (Worksheet 2)

Aims and objectives:

To facilitate access to texts dealing with energy without encumbering students with a jumble of units or exposing them to the risk of confusing energy with power.

Level: II

Subjects: Physics, chemistry, biology, English (French).

Materials:

For consultation:

- physics textbooks, encyclopaedias
- various articles on energy.

Exercises:

(1) Make a list of all the units of energy or power you encounter in your reading.

(2) Calculate the number of joules and the number of kilocalories corresponding to the transformation of one kWh of electricity into heat.

(3) Make a list of equations between all the units of energy defined in this worksheet; on the line headed t.o.e. (tonnes of oil equivalent), for instance, express the value of 1 t.o.e. in the other units.

	kcal	kJ	kWh	t.o.e.
kcal				
kJ				
kWh				
t.o.e.				

(4) Extend this table with such units as BTU, quad, hp, ev (electronvolt), t.c.e. (tonne of coal equivalent).

(5) Try to quantify the power of various electrical and other pieces of equipment (e.g. a gas boiler) and calculate the quantities of energy released in a given time.

(6) Calculate the efficiency of various processes, instruments, engines, ...

(7) People sometimes refer to 'Carnot tax' to the fraction of heat that cannot be transformed into work. Look for forms of energy to which this tax applies.

Projects:

Prepare a short guide (two or three pages) intended to help your parents and members of your community to understand the various entries on their gas bills, electricity bills, etc.

SECTION III: HISTORY OF THE UTILIZATION OF ENERGY

PRESENTATION TEXT

The age of biological energy

In prehistoric times and until fairly recently in his history, man had to rely on his own muscles to produce mechanical energy. For heating, lighting, cooking and fashioning certain materials he admittedly harnessed fire hundreds of thousands of years ago, but he was quite unable to draw mechanical energy from it.

Two milestones marked the ancient period of man's control of energy: slavery and the domestication of animals. As a result of these, some privileged groups enjoyed the use of extra human and animal muscle. Man himself can carry loads, pull or push objects too heavy to be carried, use primitive tools (sticks, cut stones, bows and arrows, etc.) as extensions of his arms. With more elaborate techniques, he was able to work a millstone, a wheel, etc. As far as animals were concerned, in the absence of harness their role was largely confined to that of beasts of burden. The most ancient types of harness (yoke resting on the horns for cattle, yoke resting on the withers for donkeys, ...) were not very efficient. Modern types of harness did not make their appearance in Europe until fairly late; they came from the East and continued to be developed until the eighteenth century.

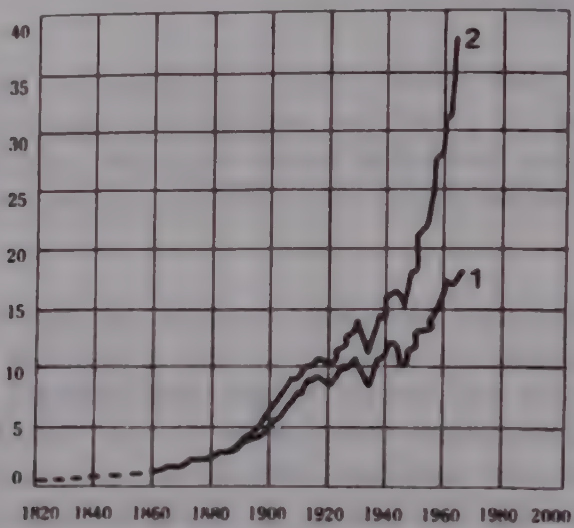
The first machines to harness the elements

Of all the non-biological forms of energy, it was probably wind energy that man learned to use first: in the sails of ships. This technique continued to be improved until the end of the nineteenth century, which saw the irreversible decline of sail in the face of steam. The windmill made its appearance much later than the sailing boat, probably at the time of the birth of Islam (seventh century); in about the tenth century, its use is documented in China and Persia. It did not appear in north-western Europe before the eleventh century and continued to be developed until the eighteenth century. While windmills were originally confined to the grinding of corn, their applications multiplied rapidly: windmills were increasingly used for sawing timber, raising water, etc. The motor power of water was first harnessed in classical antiquity, but the golden age of the water mill in Europe did not start until the eleventh century. In France alone there were 80,000 such mills by the end of the seventeenth century; they had a power of some 600,000 kW, and could potentially do as much work as six million people. Two centuries later, 70,000 of these mills were still in operation.

The age of fossil fuels

The exploitation of the traditional sources of energy reached an impasse in the late Middle Ages: lack of timber at the end of the sixteenth century in the United Kingdom, saturation use of suitable hydraulic sites (there was keen competition between the use of waterways for transport and for mill races), limited capacity of animal transport (it took hundreds of draught horses to supply some forges with timber), etc. Then, in the eighteenth century, the steam engine altered this situation radically by making it possible to convert heat into mechanical energy and to drive machines. That invention gave the signal for the first industrial revolution, which culminated in the nineteenth century with the widespread use of coal in industry and transport (railways, steamships). The mining of coal experienced a tremendous upsurge as is shown

in the table below; this was the beginning of the age of fossil fuels. For decades, the design of steam engines was constantly being improved while their efficiency rose from 1 per cent in the pioneering days to close on 10 per cent a century later.



WORLD CONSUMPTION OF FOSSIL FUELS SINCE 1820

(1 - coal; 2 - coal and oil)

It was in about 1875 that a spate of new engines appeared: internal combustion engines, electric motors, water and steam turbines.

Today, energy-transforming technologies play a major part in industrialized countries; the use of electricity has spread to all industries, to certain forms of transport (railways, tramways) and to all homes (lighting, electrical household equipment, radio, television). The internal combustion engine is undisputed master of motor transport. This development was accompanied by a change in the resources used: petrol has largely replaced coal, especially in transport; electricity from nuclear power stations may to some extent be used as substitutes for fossil fuels.

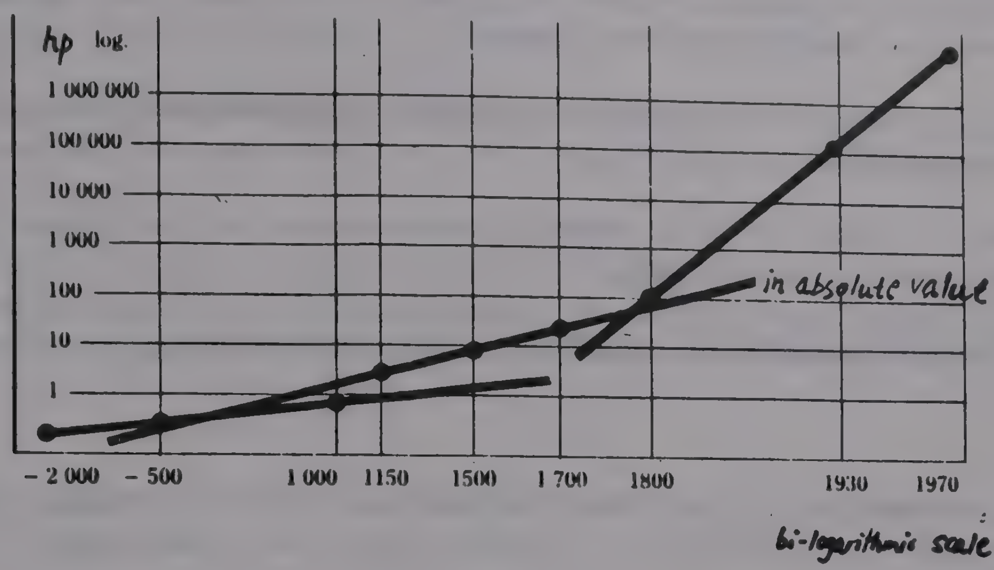
The race towards power

If we plot the power of machines available to man against time, we obtain a graphic illustration of the three periods we have distinguished in the history of energy (see graph on next page).

The following table gives the most important figures for these three periods:

Power of animals (hp)	Power of mills (hp)	Power of modern engines and installations (hp)
Ass (onager) (period of the great empires): 0.2	Water mill (17th century): 2	Newcomen engine: 10
Ox (classical antiquity): 0.3	Fixed windmill (14th century): 7-8	Watt's engine: 80
Horse (collar and shoulder harness): 0.7	Rotating windmill (18th century): 15	Power station: 10^4
		Thermal power station: 10^5
		Nuclear reactor (1982): 10^6

A great many figures can be used to demonstrate the various barriers crossed during the progress from one form of technology to the next. Most striking of all is the steep rise of the curve from the nineteenth century onwards (advent of fossil fuels), which marks a complete break with the slow pace of the past. More remarkable even than the extension of the sources of power is their amazing rate of growth.



DEVELOPMENT OF POWER (in hp) OF CONVERTERS DURING THE LAST FOUR MILLENNIA (after Meyer, 1974)

WORKSHEET: The history of the utilization of energy (Worksheet 3)

Aims and objectives:

Demonstrating the important role of energy in different societies, with the help of historical examples.

Demonstrating that various societies, their techniques and their consumption of energy, develop along similar lines.

Facilitating discussions of possible future alternatives to our current modes of energy consumption.

Level: I and II (Level I will mainly concentrate on the descriptive aspects and on simple manual operations.

Subjects: History, geography, science, art, handicrafts.

Materials:

(1) Of the documentary type: encyclopaedias, books on mills, sailing ships, steam engines, aircraft, ...; index cards or catalogues of alternative materials.

(2) Of the graphic type: line drawings, paintings, ...

(3) Of the constructional type: wood, cardboard, metals in various forms, screws, D.I.Y. tools, ... (as far as possible, use recycled materials: this is an indirect way of saving energy!).

Exercises:

(1) Try to make a graph - like the one showing the development of power - of the speeds reached by man in the course of history (walking, riding, etc. ...).

(2) Find out what other magnitudes have appeared hand in hand with the use of new sources and techniques of energy transformation.

(3) Find illustrative material on various instruments used to harness energy through the ages. Which were historically the most important?

(4) Make models of instruments or machines that were used to harness energy in the past. Do not overlook simple methods which are often more instructive than elaborate constructions.

(5) Ask the oldest members of your community what no longer extant machines they used or have seen in operation in the past. Look for such machines in museums, etc.

(6) Highlight the attitude of given societies to energy at a given period. Show the importance of energy in the life of these societies and its influence on different aspects of individual and collective life (manufacture, transport, leisure activities, homes, ...).

(7) Try to imagine future societies and the way they will obtain their energy. Discuss (possibly by means of role-playing games) the validity of the proposed solutions.

Projects:

Present to your community, in the form of a small exhibition, the energy 'profile' of a bygone society (choose a clearly defined geographical and historical case). Prepare drawings and if possible one or two models of equipment used in that society.

Organize a role-playing game with pupils in other classes or with adults on the subject of the 'energy future' of your society.

Find out if an antiquated machine might not perform a useful service even today. Draw plans of the machine, and (if possible) make a miniature or even life-size model of it.

Choose a relatively simple project based on simple techniques that could benefit a developing country or a disadvantaged group in your region. To that end, make contact with groups or associations already involved in such problems.

SECTION IV: ENERGY CHAINS AND THE TRANSPORT OF ENERGY

PRESENTATION TEXT

Energy converters

Man's problem is to control the different forms of energy in such a way as to transform crude energy economically into useful forms. This is precisely what energy converters do: biological converters - mainly green plants - no less than (man-made) artificial converters - water wheels, steam engines, nuclear power stations, etc.

The transformation of a given quantity of energy E_n from a given source (solar radiation, coal or petroleum deposits) into a quantity E_u of useful energy in the form of a particular vector (heat, electricity, petrol, ...) capable of satisfying certain needs (nourishment, heating, running a machine, etc.) depends on a chain of converters or an energy chain. In general, a chain of converters must meet three conditions. These are:

quantitative compatibility: not everything can be done with any kind of energy. That means that the final form of energy must satisfy certain needs: nourishment, heating, mechanical work, etc. It is impossible to utilize certain natural resources to good effect without special converters. Thus the heat released by the combustion of coal cannot be turned into mechanical energy without a steam engine, and wind energy cannot be converted into mechanical energy without sails or a windmill;

spatial compatibility: a human community needs energy where it lives or works, hence the need for transport;

temporal compatibility: energy requirements are subject to certain time constraints: man needs a continuous supply of food but harvests come during a brief period of the year; heating requirements are especially high during the winter, etc. To achieve this compatibility, storage and distribution systems, which themselves use up measurable amounts of energy, are needed; in general, this time constraint calls for spare storage distribution to meet peak demand and certain contingencies (e.g. climatic variations).

A chain of converters therefore enables us to transform 'untamed' into 'domesticated' energy. All the transformations along the energy chain call for an expenditure of energy on building materials, technical and industrial installations and also to cover the energy losses incurred at each step. In other words, all the operations involved, which can be divided into four phases - collection of the raw energy (capture or extraction), transport, transformation, utilization - have an energy cost of their own. The transport of energy in its various forms or the change from one form to another depends on possible energy transfers.

Energy transfers

Energy is localized in certain areas and in specific forms. Water stored behind a dam is potential mechanical energy. Chemical energy can be stored in an oil well or in food ... Nuclear energy is stored in the nuclei of atoms and molecules. In these three examples it is possible to say that 'there is' energy wherever 'there is' matter. In general, energy is transported, i.e. there is a transfer of energy by a material support, every time there is

a displacement of matter in which energy is stored. However, solar energy reaches the earth by a second fundamental method of transfer, namely radiation, which does not involve a material support.

(a) Transfer by a material support

This type of transfer occurs in the case of mechanical energy; most often it involves the transmission of motion, i.e. of mechanical energy in kinetic form, by a system of pulleys, cogwheels, gears, etc. There is also transmission by impact, for instance by two or more pendulums exchanging their energy periodically.

Heat, for its part, can be transferred in two main ways: by conduction and by convection.

In conduction, heat travels within a given medium (solid, liquid or gas) from a region of high temperature to a region of low temperature; the energy is propagated by direct contact of molecules which become displaced from their equilibirum position. The more violently they are agitated, the higher the temperature. If the average kinetic energy of the molecules in one region of matter is higher than it is in the neighbouring region - which is shown on our thermometers by a difference in temperature - the molecules with the greater amount of energy transmit some of their energy to the molecules in the lower temperature region, and continue to do so until the temperature in both regions is identical.

Convection combines conduction with the movement of a material medium. The oscillation of the particles about a mean position is generally superposed on the overall movement of matter, with a consequent transfer of energy from regions of a higher to regions of a lower temperature.

Another type of energy transfer involving a material support is that of an electric current through a wire. The current is produced by the displacement of electrons which collide at random with other particles in the wire. The collisions give rise to heat: physicists call this the joule effect.

(b) Transfer without a material support

In the case of two bodies separated by a vacuum, the transfer of energy is effected by radiation. The term radiation is applied to all sorts of electro-magnetic wave phenomena (light, infra-red radiation, radio waves, etc.) propagated at a velocity of c = 300,000 km/s. The transfer is made by a transmitter to a receiver.

The transport of energy

The various forms of energy transfer involving a material support are exploited by communities that need energy in precise locations: their homes, their places of work, etc.(1) This is a fundamental social problem. Thus obstacles to the transport of energy (of timber, for example) have for millennia been a barrier to development.

(1) Transfer without a material support also serves to 'transport' (transmit) things other than energy in the normal sense of the word, e.g. information by sound or picture.

The problem of the spatial concordance of energy with a given type of activity has been solved in different ways in the course of history: developing major transport systems, for example, in the Moslem Mediterranean for the movement of timber from Western Europe to the Middle East (seventh-ninth centuries) or of oil from the Middle East to Western Europe (twentieth century); siting a rudimentary industry close to sources of energy (water mills or nomadic industries 'following' the forest); creating a national or regional distribution network as for electricity, gas, etc.

To route energy from the deposits or transformation sites to the population centres, we need a network (tanker, fleet, pipe-lines, electric grids, ...) for conveying the 'energy-carrying matter' (oil, gas, ...) or a wave (electricity). The network itself often dissipates considerable quantities of energy. Thus, the liquefaction and evaporation of gas conveyed by methane tankers involves an energy loss of about one third. In France, the transport and distribution of electricity involve a loss of 7-8 per cent of the total output: the loss varies with the distance traversed.

WORKSHEET: Energy chains and the transport of energy (Worksheet 4)

Aims and objectives

To show that in order to obtain energy at the place and for the purpose it is needed, we must set up a 'chain' or line from the energy source to the place of use.

To clarify the notions of transfer, transport, energy vector.

Levels: I and II (I being restricted to descriptive aspects).

Subjects: Science, economics and geography, English (French), art.

Materials:

Documents: partly to be obtained from companies producing and selling energy.

Charts, graphs and other illustrative material.

Exercises:

(1) Make diagrams of various energy transfer chains, viz:

from one and the same source but for different uses;

from various sources for one and the same use;

from one source for one use but by different routes.

For each stage, describe the technical procedures used as well as the conditions, difficulties and constraints.

(2) With the help of pictures and information collected from magazines, newspapers and other sources on the subject of oil, as well as diagrams and drawings, prepare a collage showing how oil is extracted in a country from which your own obtains its supplies.

(3) Draw a map of the world showing where oil is found: for each country draw a circle of a size proportional to the quantity produced. On your map, show the transport routes to your own country.

(4) Look for documents (including photographs and drawings) depicting ships, tankers, loading, unloading and cleaning operations, and accidents that have caused oil slicks.

(5) Sketch the chain of processes leading from crude oil to the petrol we use in our cars. What special characteristics make oil an energy resource that it is easy to use ... but also easy to waste?

(6) Which are the chief methods of transporting energy? Make drawings and diagrams to represent them.

(7) Examine the causes of the losses and of the energy expenditure associated with these methods of transport.

(8) Justify the use of high tension cables for the long-distance transport of electricity.

(9) Compare the complexity of different energy chains (e.g. coal, hydro-electricity, firewood, ...) with each other. Also compare two cases of the same energy chain under different conditions (say, distance between source and place of final use in the case of firewood).

(10) Are there risks of accidents or of breakdowns along the various energy chains? Which? Of what type are they?

Project:

Prepare an exhibition on the subject of 'energy chains'. Bring out clearly the fragility of such chains, the accidents that sometimes occur and, above all, man's dependence on a system that is both complex and also vulnerable.

SECTION V: ENERGY SOURCES AND RESOURCES

PRESENTATION TEXT

The different sources of energy

A source of energy is one capable of supplying us with energy. The sources available to man are diverse. The main renewable and diffuse source of energy is the Sun, whose radiation can be used directly: heat obtained from flat-plate solar collectors or electricity from photo-voltaic cells. However, the importance of solar energy is due above all to its indirect contributions along several routes:

a 'climatic route': wind energy and hydraulic energy;

a 'biological route': photosynthesis which leads to the formation of the biomass. This is the source of our energy as heterotrophic living beings (food); it is also our source of timber which, in the form of firewood, supplies the needs of more than 1,000 million people.

Coal, oil and gas are also obtained from the (fossilized) biomass or from products derived from it: they were formed over very long periods of geological time and are therefore non-renewable resources. They represent energy in a concentrated form.

Except for some special sites, geothermal energy is a diffuse resource; it is renewable because the internal heat of the earth constitutes a considerable reserve of energy based on permanent radioactive phenomena.

Nuclear fuels such as uranium are 'burnt' when nuclear fission takes place and they are therefore an exhaustible resource. If it should prove possible to use nuclear fusion starting with hydrogen, an element that is abundant and would be deployed in quantities quite negligible in comparison with the energy produced, this resource would be practically inexhaustible.

Tidal energy is the only type of energy that depends on inter-planetary attraction (gravitational forces).

The energy of the biomass and its use by man

Our most important converters are plants containing chlorophyll, a pigment that allows the capture of energy from sunlight during the first phase of photosynthesis. That process culminates in the conversion of molecules of carbonic gas present in the air in the proportion of 3:10,000 and of water from the soil into sugars (carbohydrates) the basic material from which all the components of organic matter eventually derive. In organic matter, energy is stored in the form of potential chemical energy corresponding to the chemical bond forces. If it is not conserved as such (as it is in timber used for construction purposes), the energy can be used in various forms, and more particularly for feeding animals and man and for producing heat by combustion (mainly wood).

The mass of matter produced by chlorophyll-containing vegetable matter, be they land plants or plankton in the ocean, is enormous: approximately 230,000 million tonnes a year. But the availability of this enormous mass is not universal:

it is present only where there is water (there is very little or no vegetation in the desert);

it is a diffuse form of energy, which imposes the need for harvesting and a consequent expenditure of energy.

On the other hand, this energy resource can be renewed every year, if care is taken not to alter the characteristics of the reproductive system. Moreover, it is partly storable (e.g. in timber and certain foodstuffs).

The functioning of natural systems, called ecosystems, which can be loosely defined as 'pieces of nature' (e.g. a given forest type, a meadow, a pond, ...) is ensured by a constant flow of energy through them: in fact, animals (called first-order consumers if they are herbivores and second-order consumers if they are carnivores) find the energy they need in the chemical energy stored by living matter - green plants in the case of herbivores, and herbivores in the case of carnivores. In addition, dead or waste organic matter - often after first passing through complex chains of other living agents - is finally 'burnt up' by bioreducers (micro-organisms which return to the environment the mineral elements contained in organic matter). Finally, all living beings participate in the release of the energy contained in living matter in the form of heat (degraded energy) during respiratory exchanges.

This flow of energy through the ecosystem also helps to maintain a number of bio-geo-chemical cycles: the carbon cycle (starting with carbonic gas in the atmosphere), various mineral cycles (nitrogen, phosphorus, potassium, ...) and even the water cycle.

Man uses the biomass essentially to obtain energy in two areas:

food;

wood for fuel.

Nutrition supplies the energy needed to maintain human and animal life: respiration, muscular effort, brain functions, ... These energy needs are met by the energy values of the foods ingested (once the energy value of excreta has been deducted): in an individual with a steady weight there is a strict equality between the expenditure of energy and the intake of food.

If we remember:

(1) that the water content of foods contributes no energy;

(2) that every food is a mixture (in varying proportions) of three types of substance:

sugars (carbohydrates);

nitrogenous substances concentrated in meat and fish (proteins);

fats and oils (lipids);

(3) that man obtains the energy supplied to him as:

four kilocalories/g (= 16.7 kJ/g) from carbohydrates and proteins;

nine kilocalories/g (=37.6 kJ/g) from fats.

Moreover, if we also know the water content of a given foodstuff and the relative proportions of the three basic constituents contained in it, we can easily calculate the calorific value of that foodstuff.

For example, 100 g of wheat (containing about 10 per cent of water, the rest - 90 per cent - being carbohydrates and proteins) will have the following calorific value

$$100 \times \frac{90}{100} \times 4 = 360 \text{ kcal.}$$

One hundred grammes of lean meat which is about two-thirds water (than one-third protein) has a calorific value of

$$1/3 \times 100 \times 4 = 133 \text{ kcal.}$$

Calorific requirements are generally measured indirectly either by the quantity of oxygen needed to meet them (by combustion) or by the release of heat from the human body. They can also be determined a posteriori by computations of the energy value of the amount of food consumed (minus that of the excreta) by an adult of constant weight. For an adult doing sedentary work, the daily calorific requirements is approximately 2,700 kcal. Energy requirements vary with body weight, sex, activity, heat and cold ... The basic metabolism corresponding to the minimum essential physiological activity (respiration, heartbeats, production of body heat, ...) represents an irreducible energy expenditure; it is measured in the absence of digestion, thermal regulation and any other active processes. The basic metabolism is the minimim functioning of the human engine. Different activities demand different expenditures depending on their intensity, viz:

50 kcal/h for a sedentary life;

100 kcal/h for a moderate work;

200 kcal/h for sustained work;

300 kcal/h for intense work.

The human engine thus runs on food or, more precisely, on the energy released by the chemical bonds in the atoms of the molecules constituting that food. It is sometimes said that digestion is the slow combustion of food with the help of the oxygen we inhale. If we take the case of a simple food such as glucose, that combustion can be expressed by the following formula:

$$C_6H_{12}O_6 + 6O_6 \longrightarrow 6\ CO_2 + 6H_2O + \text{energy}$$

This reduction is the inverse of the synthesis performed by green plants, which involves the capture of solar energy. Human beings thus use the energy stored in other living things (plants and animals). The reactions involve oxygen and take place at body temperature: hence the term slow combustion. When other organic matter is burned, for instance wood, petrol or coal, the same reaction takes place but at a violent rate with the production of high temperatures. In both cases, the energy released is derived from the chemical energy of the atomic bonds. It is said that organic matter represents potential chemical energy.

New energies other than the biomass

The so-called 'new' energies are often anything but new; they have merely achieved greater prominence because of the growing need to make energy savings and the search for forms of energies less harmful to the environment than those currently in vogue. They are sometimes called soft energies.

Solar energy from physical converters

To be of practical benefit to man, solar energy must be captured and turned into a specific form of energy for a specific purpose (a specific vector). When the captors or converters are not living organisms (green plants), other techniques of capturing energy must be used. Part of the sun's radiation falls in the infra-red region of the spectrum and supplies heat; however, that heat is at a relatively low temperature and, because it is diffuse, has to be collected and concentrated if higher temperatures are to be generated.

The oldest method of using solar energy is found in buildings, where it is applied:

either more or less empirically to increase or reduce certain climatic features (so-called bioclimatic architecture, as ancient as the origins of house-building, the merits of which are being rediscovered now);

or with the precise aim of using the sun as a source of energy (passive solar architecture).

Such architecture involves a number of fundamental techniques which are combined in various ways:

(1) the greenhouse effect, based on the fact that much of the infra-red radiation passing through a pane of glass into the interior of an inhabitable space is retained in that space;

(2) the absorptive power of dark surfaces followed by the transport of the captured heat (heat-conducting fluid, warm air heating);

(3) wall insulation to reduce heat losses;

(4) the possibility of storing captured heat in various structures: concrete walls, masses of pebbles, water reservoirs; ...

(5) concentrating systems, e.g. parabolic mirrors, used as solar cookers; ...

Concentrating systems will be used especially if the aim is to generate a form of energy that can be transported and distributed like electricity: a barrage of mirrors is then used to concentrate the heat and obtain high temperatures. In that way it is possible to produce steam directly (or by means of a liquid in the form of fused salts) and hence to run a turbine that will generate electricity. The Themis power station presently in the course of construction is intended to produce 2 MW of power from 200 mirrors measuring 50 m² each.

The direct transformation of solar radiation into electricity can also be achieved with photo-voltaic cells. They are made of semi-conductors (silicon) and their efficiency is upward of 20 per cent (considerably better than the 1 per cent of energy retained by the biomass), but their price remains high

and the electricity obtained has to be stored during the hours of darkness. Panels consisting of fairly large numbers of simple photo-voltaic cells make it possible to run isolated television relay stations, airfield beacons, ... and may also be used for domestic purposes.

Indirect forms of solar energy are also very important for us, especially the energy of wind and water. It is affected by the climate, governed in turn by the movements of masses of air and the water vapour they contain. Now, indirectly, it is the sun which causes these movements, essentially by means of variations in temperature on the surface of the earth. Solar energy is also the cause of the evaporation of water from the oceans and from the earth's plant cover (transpiration). Rain water at higher altitudes tends to flow towards the sea; this difference in level is exploited in the construction of dams. The potential energy of the water stored in this way will, when freed, turn turbines that generate electricity, though the mechanical energy of water can also be harnessed more directly (flour mills, sawmills, ...). The main limitation set to this type of energy is the need for special sites which are in fact very small in number. Wind, on the other hand, is universally present but that also means that it is a diffuse form of energy and, on top of that, intermittent. Nevertheless, after man and animal power, it was, as we said, the first source of mechanical energy to be used, for instance in sailships and windmills. It meant waiting for just the right moment and though the miller was able to sleep, he had to be ready to spring into action at a moment's notice. Despite a great many experiments now being conducted, it looks as if the construction of vast wind generators with a capacity of hundreds or thousands of kW presents a difficult problem and it seems that their use will have to be confined to special regions. Small wind pumps to draw water for animals in the fields have been used for scores of years, and other local and domestic uses cannot be ruled out.

It is worth reiterating that there is also a passive method of using the sun, especially in house construction, a method not based on complicated apparatus but simply on architecture of the bioclimatic type (facing of walls, citing of windows, ...). This type of architecture, which has very ancient empirical antecedents, does not simply rely on a partial capture of solar radiation but also tries to provide protection from the cold, from excessive heat (intense sunshine) without any expenditure of energy other than that used in the manufacture of the building materials.

Tidal energy

The mechanism of the tides is complex and a detailed account of changes in their amplitude according to time and place would require long explanations. To simplify matters, we might say that the tides are the result of lunar attraction and that they occur periodically depending on the relative positions of the moon and the earth. The result is an alternate inflow and outflow at the shore twice in each lunar day with a time-lag in some places. The amplitudes (difference in sea level at high and low tides) can be considerable - as much as 18.60 m in the Bay of Fundy, Canada.

The exploitation of tidal energy is not new. As early as the seventeenth century, in the United Kingdom, water mills were driven by the ebb and flow of the tide. The construction of large-scale dams closing off estuaries or bays with large tides has been proposed on several occasions in the recent past but actual constructions are few and far between. The tidal power station on the Rance estuary near St. Malo, France, is still the only station of its type in the whole world: the 24 turbines, each of 10,000 kW, are activiated when the dam fills at high tide no less than when it empties at low tide, because the

turbines are able to run in both directions. Electricity can be generated for about four hours every day. If the electricity is being generated at a time of low user demand, the current is used to pump water back into the reservoir behind the dam thus extending the use of this hydraulic potential. More ambitious projects have been proposed for the same region, notably the closing of the Bay of Mont St. Michel between the Pte. du Grouin in the west and the Isle of Chausey in the north. But this gigantic project, quite apart from its cost, would completely alter the coastal landscape. The expected output of between 12,000 and 25,000 MW, moreover, would provide electricity that does not really seem to be needed at the moment.

Geothermal energy

An enormous amount of energy is stored right under our feet, as witness the existence of active volcanoes. It has been known for a long time that once we go down beneath the dozen metres constituting the crust of the earth, we reach increasingly high temperatures: there is an increase in temperature of 1°C for every 30-40 m we go down. This fact was first noted by miners in the seventeenth century, but it was not until the 1860s that systematic observations of the thermal gradient were first made. The source of this heat is magma, a very hot viscous liquid in the earth's crust (which solidifies to form igneous rock and is also the seat of nuclear reactions).

The Romans used thermal springs to heat their baths, and this practice is being continued in a number of countries rich in geysers (e.g. Iceland). In France, such places as Chaudes-Aigues ('the hot waters') or Dax are providing hot water at a temperature of 80°C for domestic use. They are low-energy geothermal sources: from 1990 onwards, it is hoped to heat close on 500,000 French homes from these and similar sources. In Melun, a low-rental housing estate is already being heated as well as supplied with hot water by this method. High temperature deposits (more than 150°C) are generally earmarked for the production of electricity. The classic examples are found in Lardarello, Tuscany and in the geyser basin in California, where 400 MW of electricity is produced by a field of steam extending to over 2,500 hectares. Some countries, lacking hot enough sheets of water have proposed sinking 'doublets' (two neighbouring wells): one shaft allows injection of cold water, which - heated by contact with high-temperature rocks - emerges from the second well shaft in the form of steam. Anyone proposing to use this method for long-term projects should, however, bear in mind that the constant injection of cold water might reduce the temperature of the deposit locally and hence render it useless.

Nuclear energy

This is a form of energy that qualifies for the name of 'new' but also of 'hard' because nuclear power stations are very massive and the general and accidental risks they pose to the environment incite a great many fears. To explain the origin of nuclear energy, we have to recapitulate a few ideas about the structure of matter.

If we burn wood or petrol, substances composed of large molecules (many atoms of carbon, hydrogen and also, in the case of wood, of oxygen), we essentially use the energy of the chemical bonds. But atoms are composed of still smaller particles:

a ring of electrons;

a nucleus made up of protons and neutrons.

If we look into the binding energy of these particles in the nucleus, we move into the realm of nuclear energy. Two routes are then open to us:

(1) we can 'split' a nucleus into a large number of particles: this is nuclear fission;

(2) we can 'fuse' two nuclei made up of a very small number of particles each: this is nuclear fusion.

Nuclear fission is largely based on the use of uranium-235. If a free neutron hits the nucleus of uranium-235, that nucleus is split into two smaller nuclei with a release of energy and of two neutrons which can now hit two further nuclei and so on: this is called a chain reaction. The energy released takes the form of radioactive radiation and the release of enormous quantities of heat. If this reaction is not controlled, we have an atom bomb with all its devastating effects! To produce useful energy, the reaction must be slowed down and so made to produce a constant and regular flow of heat. This is done by introducing moderators, which absorb the neutrons, into the nuclear fuel to varying depths. A large number of nuclear power stations now produce electricity by this means, using various moderators and coolants or fuels other than uranium (plutonium).

With thermo-nuclear fusion man is trying to reproduce the sun on earth! It is in fact this type of reaction which turns the sun into a gigantic and permanent hydrogen reactor which, luckily for us, is 150 million kilometres away! Fusion is the combination of light atomic nuclei consisting of just one neutron and one proton (e.g. deuterium or heavy hydrogen). The fusion of the two deuterium nuclei produces helium with a colossal release of energy. Thus a single gram of deuterium will release as much energy as does 2,800 kg of coal. But quite a few obstacles still stand in the way of this process. While it is not too difficult to obtain heavy hydrogen (one atom in 6,000 of those contained in water is of this type) or lithium (another substance that can be used in fusion), it is extremely difficult to produce the initial conditions needed to set off the reaction:

a temperature of scores of millions of degrees;

a plasma (a very dense ionized gaseous material) 'confined' inside a very intense magnetic field;

materials compatible with this type of fuel.

On the other hand, the production of energy by fusion would be clean and would not present the problem of having to store the nuclear waste created by fission. Thermonuclear fusion would, morever, have the advantage of solving the problem of limited energy resources at one stroke. By contrast, the nuclear fuels used at present seem to be exhaustible, although the use of thorium reactors renders them fairly abundant. Thorium, moreover, is less dangerous than plutonium.

In 1905, Einstein established that matter ($\underline{m}$) and energy ($\underline{E}$) are two different forms of one and the same thing and that they are quantitatively related by an equation involving $\underline{c}$, the speed of light. In normal chemical reactions which simply involve the binding energies of the atoms, matter and energy are to all intents and purposes conserved without any transformation. In the case of nuclear reactions by contrast, we observe decreases in the mass ($\underline{m}$) of the reacting nuclei and the production of energy $\underline{E}$, such that $\underline{E} = \underline{mc^2}$. Thus 1 g of disintegrated matter can theoretically provide 9×10^{13} joules of

energy, the energy equivalent of 2,000 tonnes of oil. However, in practice, the disintegration of the matter is always incomplete, so that only a small part of mass is turned into energy.

The use of nuclear energy - both for military and peaceful purposes, notably for the production of electricity by nuclear power stations - raises a large number of problems and has given rise to animated discussions and to mass protests. It is certainly a landmark in the relationship between our civilization and science and technology.

WORKSHEET: Biomass-derived energy for food and other uses (Worksheet 5)

Aims and objectives:

To show on what theoretical concepts and on what concrete processes the supply of energy to our organism is based.

To show man's dependence for his very biological survival on ecosystems, notably agro-ecosystems (see also the Worksheet on 'Agriculture: consumer and provider of energy').

Defining the energy uses of the biomass for purposes other than food.

Levels: I and II

Subjects: Biology, physics, chemistry, geography, economics, agriculture and forestry, composition, art, technical drawing.

Materials:

Documents and drawing materials.

Materials for building models and performing experiments (e.g. pressure cooker to demonstrate methanization, ...)

Exercises:

(1) Look for various models of atoms and molecules: how are the chemical bonds represented in these models?

(2) Calculate the energy of various foodstuffs from tables giving their water content and their composition in terms of the three major types of organic constituents: carbohydrates, proteins and fats.

(3) Does an examination of the chemical formulae of different kinds of organic matter tell us anything about their calorific value?

(4) Try to convey in simple words (as you might use for pupils younger than yourself or at a public meeting) some idea of the operation of the human 'machine'. Can ideas like 'fuel', 'slow combustion', 'oxidant', 'efficiency' be employed usefully in this context?

(5) Find, mainly in books on ecology, representations of the energy flow of various types of ecosystem in which the different subdivisions of the energy flow are quantified.

(6) For one of these, try to determine the efficiency of the various components of the ecosystem, notably:

the luminous energy of the sun	I
energy stored by primary producers	II
energy stored by first-level consumers	III
energy stored by second-level consumers	IV

What are the ratios II:I, III:II, IV:I?

(7) Water cycle: find out how much water is transferred by one hectare of vegetation; compare the amount of energy needed to vaporize this amount of water with the total quantity of energy supplied by the sun to the same area during the growing period and the amount of solar energy stored in the organic matter of green plants.

Projects:

Write a very simple leaflet on a balanced diet and its importance to individuals (according to age, sex, work, etc.).

Make montages and models to depict different ways of using the energy of the biomass.

State the part played by the biomass in energy consumption in your country. Could this part be increased? Does this use of the biomass have drawbacks (deforestation, erosion)? Make a display (in the form of a pamphlet or of exhibition panels) to alert your community to these problems, stressing locally important aspects:

the need for increased use of the biomass or, on the contrary, for restraint in its use;

the effects of such use; competition with other uses, ...

Devise concrete projects to implement your conclusions: e.g. planting trees, recovery of agricultural waste, ...

WORKSHEET: New energies other than the biomass (Worksheet 6)

Aims and objectives

To familiarize pupils with the principles on which the use of the so-called new energies is based.

To assess the justification of describing such energies as 'new'.

To demonstrate the possibilities and limitations of these ways of supplying energy and to encourage a critical approach.

Levels: I and II

Subjects: Science, geography, history, economics, composition, drama, technical drawing, art, handicrafts.

Materials: documents; drawing and D.I.Y. materials, salvaged articles.

Exercises:

(1) In connection with the use of solar energy converters:

make a table of the various physical methods of converting solar energy;

discuss the different physical methods of capturing solar energy. Look at the literature issued by various companies and try to judge the effectiveness of the equipment offered for sale;

draw up plans or, better still, make models or, best of all, construct an actual device for the utilization of solar energy.

(2) Write a summary of the present or past (tide mills) use of the energy provided by the tides:

calculate the attraction between the earth and the moon, having first established their mass and the distance between them. What is the mass of the water present on earth and what proportion is contained in the oceans and the largest inland seas respectively? Explain the difference in height of the tide in different places;

do some research on the location of existing or projected tidal power stations. In France, for example, the production of electricity by the Rance estuary station has been programmed to take account of tidal fluctuations as well as the daily and seasonal peak periods of demand (see literature published by Electricité de France); try to understand the procedure used. Try to devise an optimization programme that could be fed into a computer.

(3) Look for documents on geothermal energy, i.e. on:

the inner 'fire' of the earth;

natural sources of heat: volcanoes, hot springs; ...

actual methods used to exploit the heat of the earth (where, how, ...?)

Make a survey of urban heating projects based on geothermal energy.

Why is geothermal heating particularly economical indensely populated areas?

Consult a map of zones of intense volcanic activity. Why can the energy of volcanoes not be tapped?

(4) Is wind energy a new form of energy? Study the technical changes in the equipment that makes it possible, or has made it possible, to use wind energy. What are the characteristics of this type of energy? What might its future be?

(5) Other 'new' energies are the subject of more or less intensive research: production of hydrogen by different methods; utilization of the energy of ocean waves, of the difference in temperature between surface sea-water and deep sea-water, of osmosis in salt and in fresh water ... Consult documents on these subjects in an attempt to gain a rounded view.

<u>Projects</u>:

Prepare an exhibition for your community, bringing home the importance of the so-called new energies, with the help of models, calculations, etc.

Put forward a <u>concrete proposal</u> for an installation using one of these forms of energy in your school or some public building; examine the conditions of putting it into operation; check your proposals against the views of officials and the public; try to have your plan adopted and participate actively in the process.

WORKSHEET: Nuclear energy: hopes and fears (Worksheet 7)

Aims and objectives:

To define the theoretical bases of nuclear energy production.

To show that the choice of nuclear energy rests on technical information as well as on the acceptance of certain risks.

To demonstrate the difficulty of an objective assessment of the risks.

To familiarize pupils with some of the complex topical discussions and hence to demonstrate that value judgements are involved at every stage of the argument.

To bring out the long-term consequences of present-day actions and our obligations to future generations.

Level: II

Subjects: Physics, biology, geography, economics.

Materials: Press cuttings, documents released by energy-producing bodies, books, reports of political debates, ...

Exercises:

(1) Examine the theoretical bases of nuclear energy production; to that end:

look at nuclear reaction formulae; examine the implications of the relationship between mass and energy. How much fuel does a nuclear power station need in theory to produce a certain amount of energy?

go over the calculation showing that one gram of matter corresponds to 9×10^{13} joules of energy, the energy equivalent of over 2,000 tonnes of oil;

the combustion of 2 g of hydrogen, which requires 16 g of oxygen, produces 69 kcal. Calculate the loss of mass as a result of this reaction. What do you think of the result?

(2) Sum up the possibilities of energy production by nuclear fusion. Study documents explaining the technical processes involved in nuclear fusion. Apart from the technical problems, are there also problems of economic viability?

(3) Collect data on the principle of harnessing nuclear fission energy, the availability of the resource (uranium) and its renewability, the techniques used and their difficulty, the economic aspects, the effects on health, the risks, the problem of waste, the choice of sites for power stations, ...

(4) Imagine a discussion about nuclear power stations that will:

clearly set out the arguments for and against;

centre the arguments: on the economic issues
: on the risk issue;

analyse the justification of a decision in favour or against;

examine the: indisputable consequences
: more hypothetical consequences

of acceptance or rejection.

(5) The discussion in the classroom could take a role-playing form: the following dialogues might help to bring out the various attitudes:

(a) Worker: 'It gives me a good living ... I don't know if I'd find another job. Obviously, it may be dangerous but I get well paid.'

(b) Ecologist: 'Nothing can justify the risks that these power stations pose: even if the risk of an accident were minimal and of a serious accident mathematically impossible, you can't escape the fact that the reactors produce such waste products as strontium-90 and caesium-137, which remain radioactive for at least 30 years, and other waste products with an even longer life that no one knows what to do with. At present this waste is being stored in the hope that some method will eventually be found of getting rid of it for good ...'

(c) Local inhabitant: ... 'They say radioactivity is very high round the power stations ... that the result may be cancer and malformations. I have read about a study done at the Hanford atomic power station on the Columbia river in the north-west of the United States. According to that study, radioactivity in plankton has been increased 2,000 times, in insect larvae 350,000 times and in birds, which eat lots of these larvae, 500,000 times. I am very afraid, mainly because we have a large river and also because a large part of what we eat comes from our garden on its banks and because we sell a good part of our produce. When I think of the effect this could have on the children ... there is so much talk of cancer and genetic mutations.'

(d) Government spokesman: 'Nuclear power, though it still needs some research, nevertheless gives us grounds to hope that, in case of an oil crisis or any other energy crisis, we shall not be struck with paralysis. This is because, as from 1985, we shall be able to satisfy 80 per cent of our demand for electricity with nuclear power, that is 25 per cent of our total energy requirements. Nuclear energy is a necessity. What with the exhaustion of hydrocarbons and the failure to develop other forms of new energies fast enough, nuclear power is an interim source of energy that is essential for the next 50 years or so if we are to meet the needs of industrialized countries ... In the year 2000, the industrial world will have a nuclear energy requirement of 7,000 million tonnes of oil equivalent. It only needs Iran to stop production and a severe winter and we shall have an acute shortage of energy. So, all in all, it really does seem that we cannot do without nuclear power.'

(e) Consumer anxious to preserve his standard of living: '... Yes, I am for nuclear power. I know it involves certain risks, especially for those who work in the industry, and problems of transporting and storing radioactive waste. But if I am to be asked to choose between reducing my energy consumption to about a quarter and using energy from nuclear stations, I'd go for nuclear energy. I don't know how

I'd live with so little energy ... No car, no record-player, none of the household gadgets I use every day, not to speak of my stereo, telly, radio ... It would be like war-time, or "the good old days". Perhaps it would be a return to a healthier, happier life but I don't know. Right now, I prefer to maintain my standard of living ...'

(f) An historian with an interest in futurology: 'I am interested in figures. I remember two in particular from my reading. A nuclear reactor provides energy for some 20 years but it will take 2,000 years before the nuclear waste loses its radioactivity. So, if Julius Caesar had built nuclear power stations, we should still be waiting for the waste to cool down. What a gift to leave our grand-children, great-grandchildren and subsequent generations! Aren't we handing them a poisoned chalice?'

Projects:

Base this project on communication with adults in two ways:

mount an exhibition summarizing your work;

organize a debate (with or without a previous exhibition) which might take the form of a role-playing exercise, some of the roles being real; to that end try to enlist the help of a journalist, a politician, a nuclear energy technician, ...

Use what you have learned during this exercise in a discussion on the links between science and society (in a civics class, for example).

SECTION VI: THE PRODUCTION OF ENERGY

PRESENTATION TEXT

Energy from different sources must be obtained in forms appropriate to the use to which it is to be put. That is why there is an 'energy-producing' industry which supplies us with commercial forms of energy, i.e. with 'vectors' carrying the energy to where it is needed. These vectors convey:

mechanical energy;

electrical energy (which can be transformed into light and mechanical energy and heat);

heat or lack of heat (cold).

The production of mechanical energy

In general, to convert potential energy into mechanical energy, we need the intervention of heat. However, there are exceptions. Thus hydraulic energy can be transformed directly into useful mechanical energy, as indeed it has been for a very long time. Oddly enough, the rise of the steam engine did not immediately lead to the disappearance of water mills, so characteristic of industrial life in the Middle Ages. On the contrary, the water-wheel gave rise to a host of inventions and improvements that culminated in the turbine. One of the first (hydraulic) turbines developed by Fourneyron (1828) had an output of 50 hp, which was considerably greater than that of the old mill-wheels. Half a century later, in 1884, Parsons introduced the first steam-driven turbine in the United Kingdom; it was capable of direct rotation and obviated the use of cranks and connecting rods.

All in all, however, a new era opened with the advent of the steam engine. Its time is now practically over: nowadays piston-driving steam engines are hardly ever seen, their use having been eclipsed by electrical motors and internal combustion engines. All the same, the steam engine paved the way for the Industrial Revolution. It is generally believed that its most remote ancestor was the hollow sphere described by Hero of Alexandria. To that sphere were attached two bent tubes and when water was boiled in the sphere, the steam escaped through the tubes causing the sphere to whirl about rapidly. At the end of the Renaissance, a number of authors pointed out that if steam were plunged into a well inside a tube, its condensation would draw water into the tube. In 1698, Savery used this principle to build an engine that could pump water out from flooded mines. After various other attempts (Huygens, Papin, Newcomen), it was left to the young Scots engineer Watt, in partnership with the industrialist Matthew Boulton, to construct the first modern steam engine with a number of refinements (condenser, double-effect engine, regulator). Between 1775, the date when they began to operate their first two engines, and 1800, Watt and Boulton built more than 500 engines, each with an output of a few dozen horse power. Most of the engines used until the end of the nineteenth century were derived from those originally built by Watt.

In our day, the steam engine has been almost completely ousted by the internal combustion engine. In 1876, after many trials and errors, Nikolaus Otto built the first really efficient four-stroke engine; it was exhibited at the Paris Universal Exhibition in 1888. By about 1900, all the main types of internal combustion engine had been invented. Their subsequent development hinged on their various applications, especially in the transport field. The

irresistible rise of petroleum products is largely linked to that of internal combustion engines. More recently, turbo-jets have come to the fore in aviation, largely replacing the more traditional propeller-based engines. Space and military scientists, for their part, have developed rockets that are propelled by the thrust of gases generated by the rapid combustion of such fuels as hydrogen or various mixtures of petroleum products.

Some electrical effects were known in classical antiquity, but their scientific study was not begun until the ninteenth century, following Volta's discovery of the electric battery and the electric current in 1800 and the subsequent discovery by Ampère, Faraday and others of the magnetic effects of an electric current. The industrial exploitation of electricity was not begun until the last quarter of the nineteenth century.

Electricity is not available to us ready-made, as are wood, oil or solar energy. Electricity must, in fact, be culled from some primary source of energy: the chemical energy of coal, the potential energy of water stowed behind a dam, solar radiation, etc. Moreover, a machine or engine must be built to generate electricity from these sources. The best-known of these machines uses kinetic energy as an intermediary; they work on the principle that electricity is produced whenever an electric circuit moves in a fixed magnetic field or whenever a stationary electrical circle is placed in a variable magnetic field. A device working on this principle and converting mechanical energy into electrical energy is called an <u>alternator</u>. All that needs to be done is to rotate the alternator.

On the industrial scale, electricity is usually generated in power stations, classified according to the primary source used: we speak of hydro-electric, thermal and nuclear power stations. All these power stations have three sets of converters in series:

a first converter which transforms the primary energy into mechanical energy; for example:

boiler + steam turbine in a thermal power station;

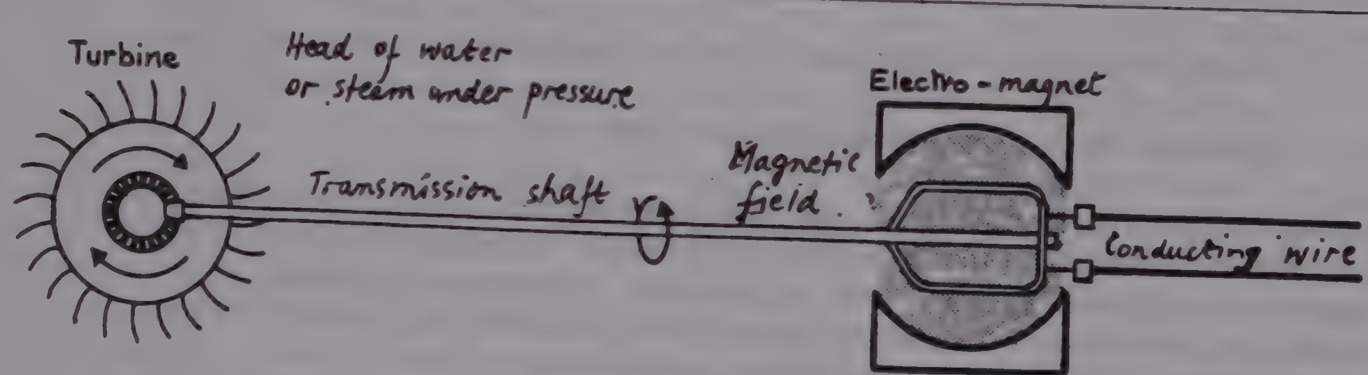
head of water + turbine in a hydroelectric power station;

propeller in a wind generator, etc. ...;

a second converter, which is the same in all types of power station: an alternator which converts the mechanical energy from the first converter into electrical energy. An alternator produces magnetic energy and the main engineering problem is to devise methods of transforming that energy into electricity without losses. After many trials and errors, Zénobe Gramme, a Belgian who had settled in France, produced the first really efficient dynamo in 1870. His device, presented to the Académie des Sciences in 1871, quickly attracted the attention of industrialists and at the Universal Exhibition held in Vienna in 1873, it was displayed to the public at large;

a third converter, the transformer, helps to raise the tension of the electricity generated so as to minimize losses from transmission lines.

Type of power station	Source	Initial energy	Converter 1	Converter 2	Converter 3
Thermal	Fossil energy (coal, oil, gas)	Chemical potential	Boiler + turbine	Alternator	Transformer
Nuclear	Uranium	Nuclear potential	Reactor + turbine		
Hydroelectric	Stored water	Gravitational potential	Head of water + hydraulic turbine		
Solar	Sun	Radiation	Solar boiler + turbine		
Wind	Wind	Kinetic	Propeller		
Geothermal	Geothermal energy	Thermal potential	Heat exchanger + turbine		



In an electric power station, the main converter is the generator which transforms mechanical into electrical energy. The diagram shows the principle on which it works. With the help of a turbine and a transmission shaft, the kinetic energy of a head of water or of steam under pressure is used to rotate a loop of wires in a magnetic field so as to induce an electric current in the loop. The current is then collected by means of stationary contact rings (known as slip rings). In industrial generators, the loop is an enormous coil of wire. Electric motors are the opposite of generators: they transform electrical energy into mechanical energy. Before putting them in operation, engineers had first to solve the same problems they had had to solve in the case of generators. In 1873, Hyppolyte Fontaine built the first electric motor worthy of the name by joining two identical Gramme machines. From that date on, there has been a veritable explosion in the use of electricity, stimulated by its vast number of applications (tramways in 1880, Swann and Edison's incandescent light bulbs in 1878, shunt windings introduced by Siemens in 1880, etc.).

The problem of transporting electrical energy has presented itself in different forms at different historical periods. The first power stations were not capable of supplying more than a small network of consumers. Two new elements changed that situation completely:

the discovery that the efficiency of power stations increases with size;

the harnessing of hydroelectricity which led to the development of generating units a long distance away from the centres of consumption.

The best solution to the problem of losses during transmission was to increase the voltage very considerably. The decisive step in this direction was taken in 1884 when Gaulard succeeded in transmitting an alternating current from the exhibition grounds in Turin to Lanzo railway station, a distance of 37 km. This system became commercially viable a year later with the development of a modern transformer. Since then, technical progress has been reflected in ever-increasing output. In France, 225 kV transmission was standardized after the Second World War; subsequently that figure was increased to 380 kV and more recently it has been proposed to introduce 735 kV tranmission lines. The long-distance transport of electricity makes possible the use of grids that skilfully combine the advantages of central and local regulation. All in all, the French electricity network now links 3,000 generators to some 23 million consumers.

At present, the generation of electricity is still based on fossil fuel resources; the proportion of hydroelectric power stations varies from country to country and some major projects in this field are being introduced or are still at the planning stage. The use of nuclear reactors is also highly advanced in some countries (France, United Kingdom, Japan, USSR, United States, etc.).

In the longer term, there are hopes of using nuclear fusion and the magneto-hydro-dynamic method (MHD), which allows the direct transformation of heat into electricity. When a loop of wire forming a circuit is displaced in the air gap of a magnet, a current begins to flow in the circuit: this is the principle of the classic generators which transform mechanical energy into electrical are based. In the case of MHD generators, the metallic circuit is replaced with a jet of gas that is a good conductor of electricity. As a result an electric current is set up in the jet. The next step would be to develop a power station whose main component is a spherical combustion chamber

into which hot air and a fuel, which is immediately burned at a high temperature, are introduced. The combustion product, the atoms of which are devoid of peripheral electrons, is then ionized; the resulting 'plasma' is forced through a nozzle and concentrated between the poles of an electro-magnet. A current of electricity is generated and collected by electrodes on either side of the jet of plasma. It is hoped that this method will make it possible to transform heat directly into electricity with an efficiency of 60 per cent, that is, much higher than that of classic thermal power stations.

<u>Producing heat and cold</u>

Combustion is the most classic and ancient method of producing energy in the form of heat. It is an exothermic chemical reaction (one that surrenders heat to the outside) and can be expressed by the following formula:

$$\boxed{\text{Combustion + oxidant} \longrightarrow \text{reaction products + heat}}$$

This reaction generally takes place in the open air and at a constant pressure close to that of the atmosphere. The fumes that escape from a fireplace contain uncondensed steam, which reduces the total heat theoretically obtainable from a given quantity of matter. The result is known as the net calorific value.

	kcal/kg
Petroleum	10,400
Methane (gas)	11,800
Vegetable oils	≃ 8,500
Coal	≃ 6,700
Ethanol	6,600
Hydrogen (gas)	24,100
Dry wood	≃ 4,000
Straw	≃ 3,000
City waste	≃ 1,700
Bituminous schists	≃ 1,100

Net calorific values of various fuels

Refrigerators work on the same principle. According to the second law of thermodynamics, heat tends to pass spontaneously from high temperature systems to systems at a lower temperature. The refrigerator and the heat pump, on the other hand, makes the calories of a 'colder' system pass to the 'hotter', thanks to the motors that supply them with energy. These motors work with a fluid, generally Freon, which goes through a cycle of changes of state:
... $\longrightarrow$ vaporization $\longrightarrow$ liquefaction $\longrightarrow$ vaporization $\longrightarrow$ ...
Every change of state is accompanied by an exchange of energy with other systems. Vaporization gives rise to a reduction of the external temperature, while the liquefaction of Freon releases heat to the exterior. The result is a thermal machine in which the fluid abstracts a quantity of heat Q_2 from a cold source at temperature T_2 and supplies a quantity of heat Q_1 to a hot source at temperature T_1. The motor has endowed the heat-conducting fluid with a positive amount of work, namely:

$$\boxed{W = Q_1 - Q_2}$$

In practice, various physical transformations of fluids can be used for refrigeration (compression, absorption, thermoelectric effect, etc.). The most common systems are based on compression. The refrigerator is a well insulated box whose inside temperature (0 - 4°C) must be kept lower than the ambiant temperature (approximately 20°C). The compressor, which runs on electricity (but can also be run on gas or oil) draws in the fluid heated with calories abstracted from the surroundings of the refrigerator and compresses it. The compressed fluid passes into the condenser - generally a coil - where it yields up its heat to the exterior, expands and reaches the evaporator at a low temperature (a few degrees). Here it once more collects heat from the surroundings of the refrigerator.

A heat pump works on similar principles though it abstracts calories from a cold source (e.g. river water, atmospheric, air, ...) and uses them to heat buildings, to produce hot water, etc. The interesting feature of the heat pump is that it absorbs calories from the cold source that are unusable in the original state and conveys them to a hot source (e.g. a building), raising its temperature.

The efficiency E_r of a refrigerator is defined as the ratio of the number of calories Q_1 pumped into the cold source to the energy W used up by the compressor

$$E_r = \frac{Q_1}{W}$$

The efficiency of a heat pump is the ratio of the number of calories Q supplied to the hot source to the energy consumed by the compressor

$$E_p = \frac{Q_2}{W}$$

WORKSHEET: The production of energy (Worksheet 8)

Aims and objectives:

To show why the energy produced from basic energy sources must be transformed into energy 'vectors'.

To distinguish the various forms of energy at their point of use.

Level: II

Subjects: Science, geography, economics.

Materials: Of the usual type, particularly documents; a discarded car alternator or bicycle dynamo; small D.I.Y. items and salvaged material.

Exercises:

(1) What combinations of methods are used to propel a jet aircraft? Rockets? Will the new engines transform traditional engines radically?

(2) What is the principle of energy conversion used in a weight-driven clock? Can it be called a motor?

(3) Find out the efficiency of electric motors and various diesel and petrol engines.

(4) Make a list of various sources and forms of energy and show how mechanical energy can be obtained from each.

(5) Make a diagram showing the underlying principles of different types of power station, e.g. (nuclear or thermal). Base your diagram on the basic layout (page 102) of a hydro-electric power station.

(6) Dismantle an old dynamo and try to identify the elements of this mini-power station.

(7) Draw the entire energy chain culminating in the production of light in a bicycle lamp.

(8) Discover the 'structure' of electricity production in your country:

sources (local and imported products);

sites and modes of production;

distribution and losses in the grid;

forms of consumption;

consumer sectors.

(9) Compare electricity with other energy vectors in terms of: transport, simplicity of use, danger, price, ...

(10) When do we deliberately produce heat for a given purpose? What are the temperatures involved? For how long? Analyse particular cases. When do we obtain unwanted heat?

(11) What is fire?

(12) Show that, in certain cases, the quantity of heat obtained is less important than the level of heat (high temperature).

(13) How does your refrigerator work? Can you cool a room by leaving the door of a refrigerator open?

(14) Why is it better to use a heat pump than rely on the joule effect to heat an apartment with the aid of an electric current?

(15) Can you write a formula covering the operation of an air conditioner similar to those we have given for a refrigerator and a heat pump?

(16) Could you produce models of different instruments facilitating the production of cold? Starting from theoretical principles, can you predict the main technical difficulties you will encounter?

Project:

Prepare a permanent school exhibit that will eventually become a teaching aid on methods of energy production. Try to make as many miniature working models as possible; failing that, prepare panels with diagrams explaining the operation of the various pieces of equipment and with clear illustrations (photographs, ...).

SECTION VII: THE CONSUMPTION OF ENERGY

PRESENTATION TEXT

Energy consumption in the home

As individuals, we are mainly concerned with domestic energy consumption because of the bills we are expected to pay for the various vectors by which energy is conveyed to our homes. Electricity, gas (piped or bottled), heating oil (tanks or drums), coal, wood and even electric batteries are the main vectors of the domestic sector. It will be noted that they all present the user with storage problems, except for mains electricity and gas.

Everyone is familiar with the use of these different forms of energy which help us:

to heat our homes (the biggest expense);

to cook our food;

to produce hot water (for baths, washing clothes, washing up, washing floors);

to light our homes;

to run our televisions and radios;

to run a large number of stationary machines, including:

household appliances (refrigerator, freezer, mixer, grinder, mincer, washing machine, dish-washer, vacuum cleaner, ...);

audio-visual equipment: slide and cine-projectors (ventilation), hi-fi systems, turntables, tape recorders, ...;

ventilation or air conditioning equipment: kitchen hods, extractor fans; hot air circulators, heat pumps.

But measuring our domestic energy consumption by our bills alone will not help us to form an overall picture; to determine our full personal impact on energy resources, we need to know:

the primary energy required to produce the energy that we finally consume at home. Thus, if the electricity we use with such ease is generated exclusively from fuel oil burned in thermal power stations, then we shall have used up almost three times as much primary energy as our electricity bills indicate;

the energy needed for all the manufacturing chains that have culminated in the objects we own: housing, furniture, gadgets, etc. Divided by the number of years that such objects and materials last, their total energy cost represents an indirect annual energy consumption which also depletes total energy resources.

When it comes to the architectural design of our homes and to town and country planning, even quite small supplementary energy investments (for instance on better insulation) can greatly improve the energy balance sheet; unfortunately, it is not always possible to procure the additional finance at the time of construction.

Energy in agriculture

If we ask a farmer about his energy expenditure, he will start off by listing:

the fuel for his tractor, for his hay-drying equipment and other machinery, ...;

electricity for lighting his farm buildings and for running various pieces of farm equipment (milking machines, washing machines, ...);

oil, gas and wood for heating farm buildings and boiling mash for the livestock, ...

This expenditure represents the direct energy consumption in the farmyard, in the fields and in some forms of transport. But there is also a hidden consumption representing what was needed to manufacture the materials used and to produce or procure fertilizers: this is indirect consumption. In 1973, David Pimentel and his students calculated the total amount of energy needed for the cultivation of maize in the United States. His results showed that whereas in 1945 a unit of energy (1 kilocalorie) yielded the energy equivalent of 3.70 kilocalories, that figure had dropped to 2.82 in 1970. That does not mean the yield or the quantity of maize produced in the United States has diminished (the contrary is the case), but simply that the modernization of agriculture swallows up increasing amounts of energy and that new energy investments in this field become less and less economical on the energy level. Besides food, which is essential to our survival as living beings - as biological 'machines' - farms also produce large quantities of organic matter in the form of waste products: unharvested or unused parts of plants, unwanted animal by-products. This agricultural waste can be used to produce energy in different ways: by combustion (straw boiler), by gasification and by methanization (production of gas from dung). This is yet another way of using the solar energy stored in the organic matter constituting the living world.

Energy in industry

All the industrial products we use have consumed energy in the course of their manufacture. The energy invested in them clearly depends on a number of parameters: raw materials, technology, distance between the point of production and the point of consumption ... However, studies covering large numbers of industrial sectors enable us to tell with a fair degree of accuracy what energy investments are needed for the most common industrial products or consumer goods, at least in the industrialized countries. Here are some examples (all expressed as tonnes of oil equivalent per tonne of product):

Industrial products

Metals	Aluminium Copper Steel	from 4.9 to 6.7 from 0.9 to 1.3 from 0.7 to 1.0	t.o.e./t t.o.e./t t.o.e./t
Building materials	Cement Glazing Wood	0.11 0.50 from 0.05 to 0.15	t.o.e./T t.o.e./T t.o.e./T
Fertilizers	Nitrates Phosphates Potassium	1.89 0.82 0.22	t.o.e./t t.o.e./t t.o.e./t

Consumer goods

Motor car (1 tonne)	1.5 to 2.0 t.o.e.
Plastics	1.7 to 2.0 t.o.e. depending on type
Washing machine	0.22 to 0.35 t.o.e./t

It should be noted that, for about a decade, great efforts have been made to reduce the quantities of energy spent on unit product. These efforts have also resulted in an appreciable reduction of energy per unit of Gross Domestic Product. According to various studies (Report of the French Planning Commission, Leach's study in the United Kingdom, that of the Oko Group in the Federal Republic of Germany), it should be possible to save a further 15 to 40 per cent of the primary energy requirements of industry from now until the end of the century, depending on the sector concerned.

Energy in transport

Waterways and roads

The first material problem to be solved in connection with the exchange of goods between men is that of transport. Water transport has traditionally been the preferred means, especially for conveying heavy loads. Make-shift boats were built very early on in the Middle East. Deep-sea navigation calls for solid vessels and the first of these were built by the Phoenicians and their model continued to be used until the Middle Ages. Land traffic, in spite of its difficulties, is essential for gaining access to inhabited localities, linking estuaries, etc. The most common means of transport, after human porterage, were beasts of burden, equipped with pack-saddles. Carts, which

made their appearance after the invention of the wheel in Egypt in about 1600 BC, could not at first take heavy loads. The invention and popularization of the shoulder-collar and later the improvement of roads made land transport gradually easier, but all the same, water transport continued to be preferred whenever possible. That is because it uses up very little energy, as is shown in the following table of the tractive power of horses:

Pack horse		0.125 tonnes
Horse harnessed to a cart	on a track	0.625 tonnes
	on a made-up road	2 tonnes
Horse towing a barge	on a river	30 tonnes
	on a canal	50 tonnes

Steam engines and railways would, of course, alter this situation. During the period of revolutionary change they ushered in, the cost of transport fell by 40 per cent. After the nineteenth century, which was considered the age of the railway, came the twentieth, the age of motor and air transport, which once again transformed the displacement of men and goods.

A plurality of transport systems

The spread and development of transport networks has been extremely uneven in different parts of the world. In industrialized countries, road transport is generally the most important form despite its disadvantages: city congestion, atmospheric pollution and, above all, poor energy efficiency compared with rail transport, as is shown by the following table:

Means of transport	Km traversed per litre of fuel	Number of passengers	Passengers x km/litre of fuel
Motor car	10 (a)	2	20
Motor bus	2.3	40	100
Jet plane	0.06 (b)	150	9
Electric train	0.8	600	480

(a) Urban cycle.
(b) Mean consumption by air lines in 1980.

Energy efficiency of various means of transport

Unlike us, most Indians, Chinese and Africans still rely largely on their own muscular energy to move about. In rural areas of many Third World countries, porterage is still the most common means of transport, often at a painful cost in physical effort. When animals replace man, especially for traction, they often do so with a low efficiency, because of badly designed harness and the poor state of the roads.

Generally speaking, speed is a luxury which only industrialized countries can afford, and energy for transport is one of the least equitably shared commodities in the world. Americans use up as much energy for their personal transport as India and China combined consume for all purposes!

WORKSHEET: Energy in the home (Worksheet 9)

Aims and objectives:

Discovering the importance of energy in everyday domestic life.

Identifying the types of energy used in everyday life (excluding the basic source of energy: food).

Levels: I and II

Subjects: Science, geography, economics, art.

Materials:

Paper for taking notes and making drawings.

Dictionaries, encyclopaedias, reference works on energy.

Illustrated magazines and mail order catalogues for clippings.

Exercises:

(1) Make a plan of your appartment or house; colour it as follows:

red: for everything that consumes energy;

orange: for everything that stores or conducts energy;

yellow: for everything that needs energy in its manufacture;

green: for everything that needs solar energy converted by green plants.

(2) Make a strip cartoon illustrating your day from the time you get up in the morning. Include every occasion you use energy.

(3) Review the types of energy (vectors) used in your home. For what purposes are they used? In what forms?

(4) Estimate your domestic energy consumption

by looking at the power rating of the equipment you use and the length of time you use it;

by examining the invoices for the various energy vectors brought into your home (electricity, gas, coal, fuel, oil, wood, ...);

by using a single unit of measurement: e.g. the kilocalorie.

(5) Think about how you would set about determining your indirect domestic consumption of energy.

(6) How does energy reach you?

(7) What are the initial sources from which the energy you use is derived?

(8) Imagine a day without electricity. Imagine a month without electricity. With what would you try to replace this form of energy in its various uses? (Draw strip cartoons to illustrate such situations)

(9) How would you make savings in energy in the home?

Project:

Prepare an exhibition for your parents and members of your community on the use of energy in the home; this could include the following:

(1) a map of your district (or, if necessary, of a wider region), showing how the energy you use is produced (e.g. hydro-electric power station) and by what means it is brought to your home (electric cables, ...);

(2) a plan of your house, marking all the locations in which energy is used (e.g. electric points, gas outlets, etc.), the equipment used, the function of each item, etc.;

(3) Explain how energy savings can be made in the home;

(4) describe alternatives for certain uses of energy.

WORKSHEET: Energy outside the home: the building and manufacturing industries (Worksheet 10)

Aims and objectives:

Reviewing the principal ways of using energy other than for direct domestic consumption. To that end, make a special study of the building industry in a town, and compare your results with those obtaining in industry at large.

Bringing out what types of energy consumption in a given society affect the individual, if only indirectly.

Drawing attention to possible alternative ways of obtaining energy from sources other than those most in use at present and likely to be exhausted.

Levels: I and II

Subjects: General subjects, geography, economics, art.

Materials: Normal classroom and drawing materials; documents.

Exercises:

(1) Make a very large map of your district or village; make very simple black line drawings of everything in it (leaving out people).

(2) Colour in red everything that needs energy to run.

Colour in orange everything that took energy to be produced.

Colour in blue everything that took no energy in its manufacture or operation.

Colour in yellow everything that can be run on, or has been made by, human labour alone.

(3) Add, if you like, small symbols to indicate what form of energy has been used.

(4) Discuss with your teacher the different results you might have obtained had you been assigned to other working groups.

(5) Apply these exercises either to a modern society different from yours or to an ancient society (prehistoric, mediaeval, ...).

(6) Draw a plan of the energy flow in a city. Try to quantify the elements of this flow.

(7) Choose a large manufactured object, say a motor car, and try to retrace the energy chain and the materials that have gone into its manufacture.

Summarize your work in a large diagram showing what raw materials are needed at each stage of the manufacturing process, what energy is required and the share of human labour.

(8) Look for documents:

illustrating the industrial uses of energy;

showing the energy consumption in the various sectors of industry.

(9) Look for data on the energy costs of all the materials that go into a motor car.

Projects: (more elaborate for Level II)

Find documents showing the consumption of energy in various sectors of the economy: agriculture, industry, transport, ... Prepare an exhibition panel showing these results in simple fashion.

Examine what new forms of energy could replace energy sources that are being exhausted: geothermal energy, wind, solar energy, the biomass.

For each of these draw up a brief list of advantages and drawbacks and of possible practical difficulties.

WORKSHEET: Energy and agriculture (Worksheet 11)

Aims and objectives:

To bring out:

the direct and indirect consumption of energy by agricultural systems;

the possibility of using certain agricultural waste products or certain crops specifically planted for that purpose, to procure energy.

To recall that the energy of foodstuffs (agricultural products) is essential to man's survival.

To demonstrate that the development of agricultural methods faithfully reflects the development of energy usage.

Levels: I and II

Subjects: Biology, geography, economics, art.

Materials: Usual classroom material, drawing material, documents.

Exercises:

(1) Produce a very large map of a rural area surrounding a village. Sketch everything found in it (leaving out people) very simply in black outlines. Colour in red everything that needs energy to run; in orange everything that conducts or stores energy; in yellow everything that took energy to be produced; in blue everything that needs no energy for its manufacture or operation, and in purple everything that takes nothing but human labour to be made or to operate. If you like, use small symbols to show what form of energy has been used (electricity, ...).

(2) Explain how the agricultural sector consumes energy (make sure you include direct as well as indirect consumption) and also how it produces it. What do we do with this energy? In what way is this energy vital to us?

(3) Can agriculture play a part in the production of renewable forms of energy? What precautions must be taken to ensure that such sources of energy remain renewable? By what methods can agricultural produce be turned into energy?

(4) Try to prepare a balance sheet for a farm and then to determine the energy balance (see Appendix II).

(5) Repeat Exercise (1), but for either a modern rural society different from yours, for an ancient society (prehistoric, mediaeval, ...) or even for the society you would like to live in.

(6) Examine the agricultural methods and the associated energy consumption of different societies past and present.

Project:

If you live in the country, make a list of energy outlays with a view to reducing them. Produce viable alternative solutions. In particular, bear in mind the possibility of using waste matter.

If you live in a town, try to devise teaching materials for groups of children knowing little about the countryside, to show them how dependent they are on the rural world and to what a large extent agriculture itself depends on the use of energy.

WORKSHEET: Energy in transport (Worksheet 12)

Aims and objectives

To identify various means of common transport.

To compare the energy expenditure involved in different forms of transport (by listing them in descending order of energy cost).

To encourage reflection on possible energy savings.

Levels: I and II

Subjects: Geography, mathematics, science, economics, history, art.

Materials: Paper for drawing and for taking notes; maps of the district and town.

Exercises:

(1) Mark on a map the routes some of you take from home to school; indicate by what forms of transport.

(2) For the same routes (or for some of them) compare the direct energy expenditure per head on different forms of transport, i.e. going

- on foot
- by bicycle
- by car
- by bus
- by train

bearing in mind the total energy consumption and the number of passengers carried.

(2a) You might also evaluate the indirect energy costs based on the weight of the vehicle used and its working life.

(3) Classify various forms of transport in terms of energy expenditure. Discuss the use of these forms of transport in terms of the distance that needs to be covered and the pros and cons of each of them.

(4) Work out a transport plan for your town, district or village and neighbourhood that would result in energy savings. For example, what needs to be done to enable everyone to come to school by bicycle? Who is responsible for traffic and transport problems in your district, town or area? Try to meet local officials and get them to explain the difficulties, constraints, choices and future plans.

Projects:

In your class, school or college, organize a debate on transport problems and on the energy consumption associated with them:

(a) as far as they relate to you directly as a member of your community;

(b) as far as they effect the economy of your country as a whole.

Try to determine how some of the dominant features of our civilization (e.g. the importance of the motor car) affect the control and conservation of non-renewable resources.

Specify the various ways in which you, as an individual, can effect energy savings in the transport field. Apply such methods and try and persuade your family and friends to do likewise.

SECTION VIII: THE ECONOMICS OF ENERGY AND ENERGY SAVINGS

PRESENTATION TEXT

Before the industrial revolution, man had to rely almost exclusively on renewable types of energy derived more or less directly from solar energy through:

the elements: wind, water power;

the biomass: fuel and foodstuffs, and hence animal traction and human labour.

Industrial society grew up on the exploitation of non-renewable fossil resources, first coal, then petroleum and gas and finally fissile minerals (uranium). The effort needed to reach these resources is relatively slight, not only in financial terms, but also in terms of human labour and cost. In financial terms, this means cheap energy, which has encouraged the development of industry but also of various forms of waste and negative effects on the human environment (pollution, noise, accidents, ...). Economic systems at large are profoundly affected, even ruled, by energy economics, their position differing radically according to whether they are made up of pure producers, of mixed consumers and producers, or of pure consumers. The recent oil crisis has underlined the dependence on the energy sector of all countries - especially, of course, the most highly industrialized of them - as well as how delicately balanced this dominant sector of the economy really is. It also became apparent that there was no real control of resources and that the so-called 'economic laws' do not act as regulators; on the contrary, present-day economic practices lead to a squandering of resources and produce a host of associated problems: pollution, noise, irreversible damage to the natural environment (desertification, deforestation, soil erosion, ...). The problem of useful resources is essentially that of usable energy.

The situation is, in fact, paradoxical: on the one hand, we are swimming in a superfluity of energy with one source, the sun, being, on our human scale, inexhaustible and in theory capable of supplying 10,000 times the energy our planet needs and, on the other hand, we are suffering from an energy crisis.

Now, if there is indeed a crisis, it concerns useful energy, its cost and its application. There is a crisis if I have no petrol to put into the tank of my car, if the coal merchant has no stocks to satisfy my heating needs or if I am no longer capable of paying for either. Before a source at the beginning of an energy chain can yield a convenient energy vector carrying the energy to where it is wanted, that energy must first be rendered usable and accessible.

For example, coal is a source of energy that is easy to use because any lump of it can be burned, but a deposit that is too fragmented or too deep is not easily accessible. By the same token, biomass is produced over large surfaces of the globe but access to that source is limited by several factors:

competition for space between different types of edible crop on the one hand, and crops planted for energy, on the other;

the need to harvest and transport this diffuse resource;

the obligation, if its renewable character is to be preserved, not to remove more than can be produced every year (if this is not done, the structure of the forest, the quality of the soil, ... will be impaired);

the cost of harvesting.

The technical methods needed to tap an accessible source of energy are generally ready to hand or easily produced, but a number of economic and other constraints (cost and energy-effectiveness) must be taken into account as well: for example, it is possible to spend more energy on an energy chain than it will ultimately yield. This might be the case with some methods of turning sugar-beet into alcohol.

One of the major aspects of the current energy crisis is linked to the increasing cost of transforming energy resources that cannot be used in their raw state or that are increasingly difficult to reach, into useful energy.

Two main recommendations to improve the energy economy have been made in response to the energy crisis: (a) resorting to 'soft' or new forms of energy, and (b) adopting an energy-saving policy. In the first case, we come up against a number of constraints:

sun, biomass, wind, sea, ... provide us with diffuse and sometimes rather limited forms of energy (biomass);

nuclear energy depends on a non-renewable resource;

the really new form of energy we may expect to derive from nuclear fusion is still no more than a promise.

Energy savings can bear on direct as well as on indirect consumption. The general public is more aware of the former because it knows only too well how much it spends on electricity, gas, fuel oil, petrol. etc. But every citizen also consumes what energy went into producing the motor car, the paper, the bridges, the roads and the buildings he uses. That is why a genuine energy-saving policy based on prudent management of our resources would lead to far-reaching reforms of our system of production and consumption and to putting more stress on development not necessarilly based on growth for growth's sake and often tantamount to squandering resources. It is easy to see that the manufacture of goods of more durable quality, while giving the same satisfaction to users, would result in a reduction of the consumption of material, of working hours and also, of course, of the energy consumed.

WORKSHEET: The economics of energy and energy savings (Worksheet 13)

Aims and objectives:

To make it clear that with energy, as with all goods, the main problem is access to the resources and their rational management.

To discourage the squandering of energy and to show that savings can be made in direct as well as in indirect consumption.

Level: II

Subjects: Economics, geography.

Materials: Economic and statistical documents; leaflets written for the general public by various public or semi-public bodies.

Exercises:

(1) Identify the sources supplying your country with energy. Distinguish between renewable and non-renewable types of energy.

(2) How are various energy sources in your country appraised? Ask specialists to explain.

(3) Do the same for imported forms of energy. What are the available resources? On what factors does the supply of these forms of energy to your country depend?

(4) What is the present proportion of imported energy in your country?

(5) What proportion of the energy from a given resource goes to the industrialized countries, to such large countries as the United States, to your own country, to the so-called developing countries?

(6) Devise a game (card game, computer game) in which limited stocks of material, time, labour and energy must be distributed for:

- maximum waste;
- penny-pinching economies;
- rational control.

(7) Find out the main ways of reducing energy consumption in industry. Which of these could reasonably be described as energy savings?

(8) Identify the main ways a country can save energy, foreign currency and materials, bearing in mind the need to maintain a certain level of production.

(9) Choose an example of energy savings and calculate the energy efficiency of the investments made and also the financial returns.

Project:

Devise a detailed energy-saving plan for your community. Concentrate above all on reducing direct consumption, but remember that much energy can be saved by cutting back on indirect consumption as well.

APPENDIX I

ADDITIONAL COMMENTS ON SOME BASIC CONCEPTS

CHAPTER I: ENERGY: ESSENTIAL DEFINITIONS AND CHARACTERISTICS

I. IN SEARCH OF A DEFINITION

An examination of some of the many definitions of energy shows how hard it is to arrive at a clear and accurate one. In his recent Vous avez dit énergie, C. Bienvenu has listed various definitions of energy given in French dictionaries and encyclopaedias; below we quote his attempts to answer the question: 'But what is energy?'

'To ask this question is not as silly as it might seem. Just put it to those of your acquaintances who feel free to hold forth on the subject. You will be surprised how vague their answer is, if they have one at all. But what do the experts have to say?

- Encyclopédie des Sciences et Techniques: "For an isolated system, we can construct a function $E = fa_i(t)$ such that $E = const$. E is therefore a characteristic magnitude of the system under consideration; it is the energy of the system."

- Encyclopedia Universalis: "In all transformations studied in physics, the concept of energy plays a fundamental role. It crops up first of all in mechanics where it means the ability to do work ..."

- Quillet: "Energy, as defined in physics, is an abstract concept associated with all manifestations of force, movement, heat, gravitational, magnetic or electric fields, etc. The concept, originally defined in mechanics as the ability of a body to do a fixed amount of work in a given system, has since been greatly expanded ..."

- Robert: "Everything that does work, is derived from work or results in work."

- Petit Larousse: "The ability of a system of bodies to do mechanical work or its equivalent."

- Grand Larousse: "The ability to do work."

All these definitions which, moreover, are far from exhaustive, do little to lift the confusion of non-specialists. Two terms keep recurring, namely "work" and "system". That is because the concept of energy was originally associated with the work done by mechanical systems. Its extension to heat, to electricity, to radiation, to chemistry is relatively recent and involves abstract ideas, less accessible to common sense than "work".

Only the Encyclopedia Universalis mentions "transformation", a word that, in my view, is a prerequisite of all correct definitions of energy. Here is my own:

Energy: What must be supplied to or removed from a material system in order to transform it.'

FRAPNA (FRAPNA: Fédération Rhône-Alpes de Protection de la Nature = Rhône-Alp Federation for the Protection of Nature) in an undated booklet entitled 'Why save energy?', puts it as follows:

> 'What is energy?
>
> Everyone knows more or less what it is but no one can tell you outright. Energy is something that intervenes in the universe every time there is a change. Rather vague isn't it? Let us take a few examples: the rays of the sun carry (electromagnetic) energy which, when absorbed by the oceans, heats them up (thermal energy), evaporates some of the water and carries it to the mountains (potential mechanical energy) whence the water eventually comes down again giving up its (hydraulic) energy to turbines which produce electricity, etc. In one disguise or another, energy is constantly being transformed, so much so that one might think this process will continue indefinitely (principle of the conservation of energy). In fact, however, every transformation involves a loss of energy, that is, renders some energy useless for the rest of the transformtion cycle (principle of the degradation of energy). It is a fundamental law of physics that the greater the flow of energy in a system the more rapid the degradation of that system.'

We shall conclude with the following quotation from a pamphlet published by CAMIF(1) on the insulation of houses. It illustrates the danger of attempts to arrive at too simple a definition; try to read this passage tongue in cheek and perhaps write a parody of it:

> 'Energy:
>
> On earth, every object left to itself will naturally drop down. Man must supply muscular work to restore it to its original position. This example refers to a particular form of energy, namely mechanical energy. In fact every object contains a certain amount of energy thanks to the force of gravity. That energy, called "potential" energy, varies with height and is measured by the latter. It is impossible to find energy in the broader sense other than by philosophical speculation. If we narrow the concept of energy down, we can describe some of its forms mathematically: by the mathematical functions of certain variables that permit the calculation of variations. Energy is protean: mechanical, chemical, nuclear, calorific and it certainly also exists in forms we do not know.'

This incursion into the many attempts to define energy leaves one perplexed. That is because the word energy is an abstract concept and hence difficult to grasp, whereas the effects of energy, the uses to which we can put it, are familiar to us. For convenience sake, we can adopt the following formulation, one that is found in most dictionaries:

Energy is the ability to do work

Starting from this, we can either look for a more precise mathematical definition or else content ourselves with a brief reference to the existence of different forms of energy.

(1) A very important co-operative of teacher-consumers in France.

We can also adopt an alternative definition, one that is more general and certainly more abstract, namely:

> Energy is what must be supplied to, or removed from, a material system in order to transform it.

II. THERMODYNAMICS, THE SCIENCE OF ENERGY

1. The scope and approach of thermodynamics or the science of energy

Thermodynamics is the branch of physics concerned with exchanges and transformations of energy. It therefore covers a very wide field, since energy intervenes whenever anything happens in the physical world, that is, whenever a material object undergoes a chemical or other change or, more generally, a set of closely related changes. Thermodynamics was born in the nineteenth century with the study of the thermal phenomena associated with certain displacements (the work of Joule, Rumford, ...) and of the operation of engines that exploit heat (Carnot's On the motive power of fire, 1824).

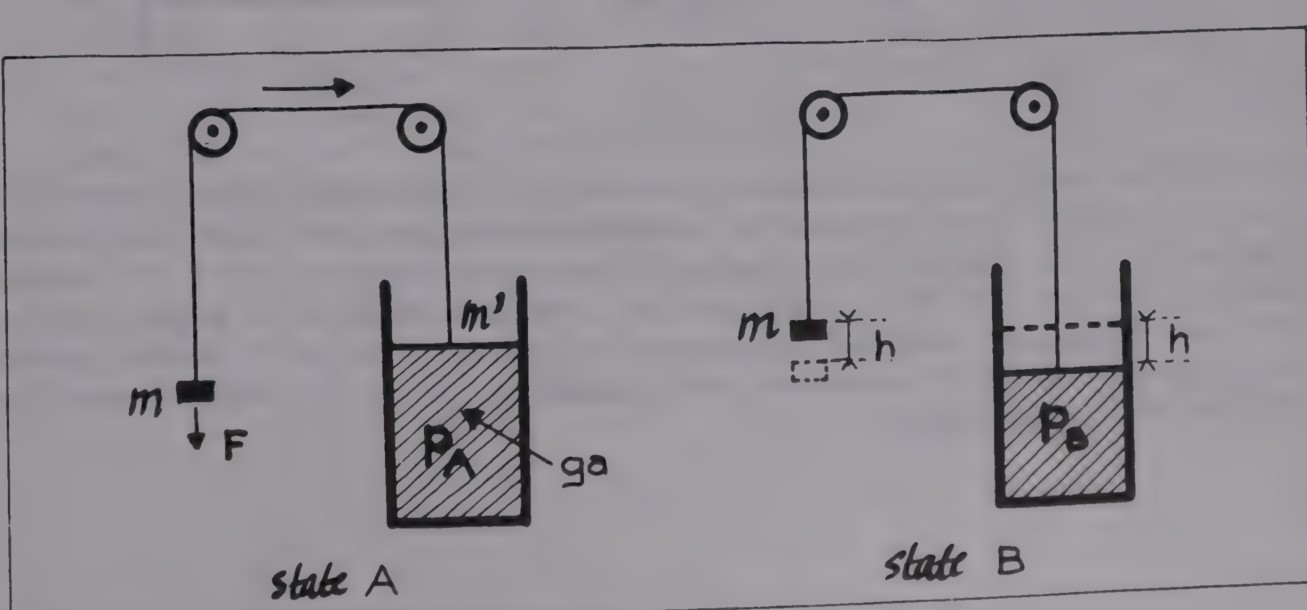
In thermodynamics, we mostly consider a set of objects or a system in the process of transformation. At any given moment, the system is in a given state, defined by the numerical values of a number of variables (the temperature and pressure of a gas, for example). Generally, when we describe transformations of entities outside the system in thermodynamics, we divide the universe into two parts: one is the system in respect of which we study the transformation and the other its environment (the exterior). The exchanges between a system and 'its' exterior can most often be reduced to:

mechanical work;

heat exchange.

2. Mechanical work and heat exchange

2.1 If a system is displaced under the action of a force, the changes experienced by the system can be expressed as quantities of work: thus, I can compress a gas by exerting a fixed amount of muscular force or by the displacement of a weight in the gravitational field (see figure below).



A quantity of gas is contained in a cylinder closed with a piston. The weight (mass) m' is greater than the weight m. In state A, equilibrium is maintained by applying a force F, directed downwards, to the weight m. The equilibrium equation can then be written as:

$$F + m + p_A S = m'$$

where p_A is the pressure of the gas in state A and S if the section of the cylinder. When we remove F, the weight m will be lifted through a height h, as m' descends through the same distance; m' settles in a position corresponding to state B. The new equilibrium equation can be written:

$$m + p_B S = m'$$

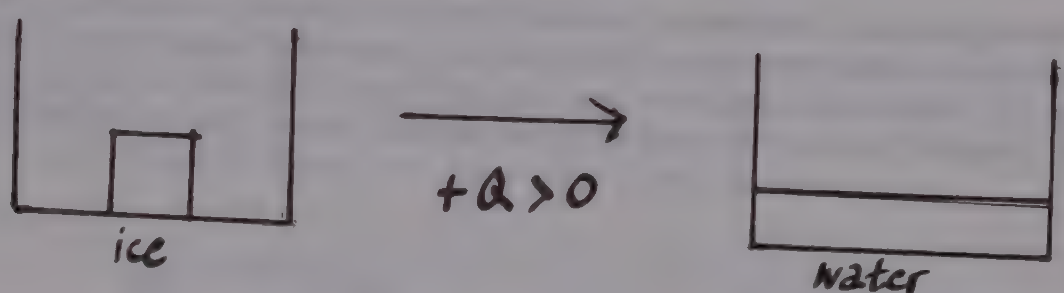
where p_B is the pressure of the gas in state B. In changing from state A to state B, the gas has received an amount of work W

$$W = m \times h$$

W>0: the work is said to be positive, the system is a receiver,
h: displacement of piston.

If, during the transformation, the system has received a quantity of work from the outside, that work is said to be positive, and we speak of a receiver system. If, on the contrary, the system has surrendered work, that work is said to be negative and we speak of a motor system. Work can always be reduced to the vertical displacement h of a weight m in a gravitational field and is expressed in the form of a product: W = m x h.

2.2 Transformations of the system can also be expressed as heat exchanges: heat can be surrendered to the outside and vice versa (see figure below).



The system consists of a block of ice at 0°C (state A) in a room at 20°C. The ice melts, and gradually turns into water at room temperature (state B). The system has changed from state A to state B by receiving a quantity of heat Q from the outside. The convention of signs is the same as that chosen to express exchanges of work. Q is said to be positive if it is received by the system but negative if it is surrendered by the system to the exterior.

We say that a system is thermally insulated if it cannot exchange heat with the environment. It is said to be insulated if it is insulated mechanically as well as thermally, that is if its transformations have no effects on the environment.

3. Temperature

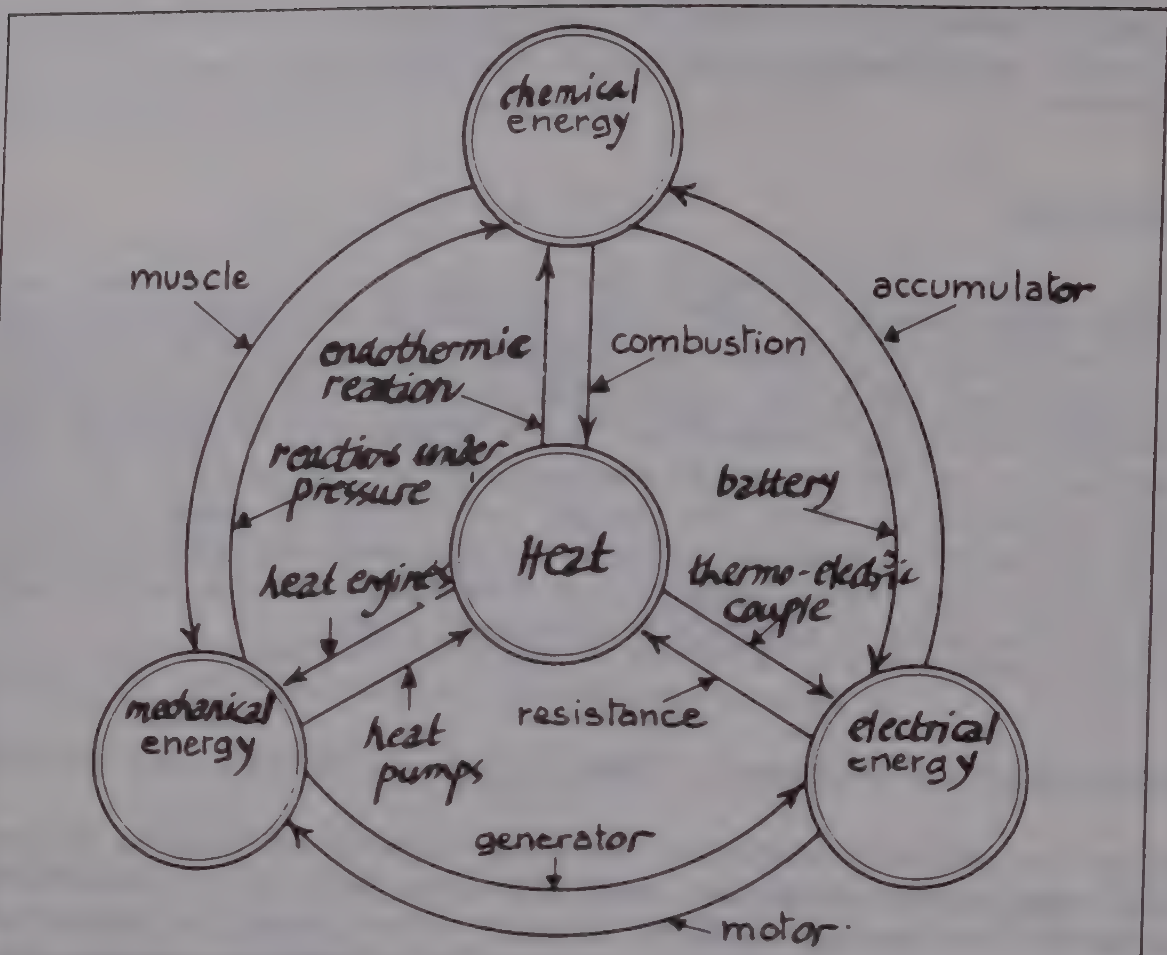
It is a matter of experience that if two material systems are placed in contact, the heat always 'flows' from the hotter system to the colder. Temperature is a variable that makes it possible to discover the 'coldest' or the 'hottest' point and hence to predict the direction of thermal exchanges. It is a very special variable inasmuch as it is impossible to add the temperatures of two bodies or of two material systems; if we add a litre of water at 40°C to a litre of water at 10°C, we obtain two litres of water at 25°C (because the number of calories remains constant). The only definable relations between two temperatures are their equality or inequality. We can only compare temperatures by reference to a carefully graduated scale.

III. CHARACTERISTICS OF ENERGY: FORMS, MODES OF TRANSFER AND TRANSFORMATION

Energy is involved whenever anything happens in nature. We have already identified two forms, which are also the two modes of transferring energy: heat and work; but energy appears in many other forms as well. Thus the sun sends us radiant energy, which is propagated through a vacuum, without any material support, and at the fabulous speed of 300,000 km per second. That energy is transformed into heat when it meets a material obstacle. If the obstacle is the surface of a lake or an ocean, the heat causes evaporation of the surface layers. The water vapour is lifted up by rising air currents and winds and may later be condensed in the form of clouds which fall back as rain and fill rivers and dams (potential energy), and can then be used to activate turbines (kinetic energy) and so to produce electricity (electrical energy). The resulting electrical energy, conducted by high-tension wires, can be used to run motors (mechanical energy) or to supply light (radiant energy) and heat (thermal energy).

This example shows that energy can appear in many distinct forms. Except for radiant energy, all forms of energy need a material support.

This material support is the atomic nucleus in the case of nuclear energy, the molecular structure in the case of chemical energy, and big 'systems' (clouds, water reservoirs) in the case of potential energy. At the nuclear or molecular levels, energy is measured on a microscopic scale, in the case of dams, it is measured on a macroscopic scale. The Thiring diagram (figure below) illustrates the interrelationship of some of the forms of energy which we have mentioned, and also some of the devices that enable us to transform one form of energy into another.



Thiring diagram

IV. UNITS

1. The multiplicity of units

To specify the quantities of energies involved in the various transformations we have mentioned, we need a clearly defined and invariable 'universal' standard of reference. The official unit of energy in the joule: the energy needed to raise a mass of 100 grams through one metre. In theory, it is the only unit - with its multiples and submultiples - we need to use, but it is often more practical to resort to other units. Thus the calorie is the most convenient unit for measuring quantities of heat: one calorie is the energy (quantity of heat) needed to raise the temperature of 1 g of water from 14.5°C to 15.5°C; its mutliples, the kilocalorie (1,000 calories) and the therm (100,000 Btu) are also in common use(1).

The most common unit used to measure electrical energy is the kilowatt-hour (kWh), the energy used in one hour by a device consuming one kilojoule (kJ) per second. Heating engineers often use even larger units, for instance the t.o.e. which is the thermal equivalent of one tonne of oil or the t.c.e. (tonne of coal equivalent). National consumption is often measured in millions of t.o.e. or in quads (quadrillions - or 10^{15} Btu; one Btu = British thermal unit = 0.293×10^{-3} kWh; 1 quad is equal to approximately 25 million tonnes of oil equivalent. Nuclear physicists who study the microscopic structure of matter use a very small unit of energy, namely the electron-volt; it is the kinetic energy acquired by an electron losing one volt of potential (1 eV = 1.6×10^{-9} J).

(1) For a long time people have also been using the large or kilocalorie: 1 Cal = 1,000 calories = 1 kilocalorie.

	Joule	Calorie	kWh	t.c.e.	t.o.e.
Joule	1	0.24	2.78×10^{-7}	3.4×10^{-11}	2.3×10^{-11}
Calorie	4.18	1	1.16×10^{-6}	1.4×10^{-10}	9.7×10^{-11}
kWh	3.6×10^{6}	0.86^{6}	1	3.3×10^{-4}	2.2×10^{-4}
t.c.e.	2.93×10^{10}	7×10^{9}	3×10^{3}	1	0.67
t.o.e.	4.3×10^{10}	1.03×10^{10}	4.5×10^{3}	1.5	1

CORRESPONDENCE BETWEEN THE PRINCIPAL UNITS OF ENERGY

Submultiples		Abbr.	Multiples		Abbr.
10^{-3}	milli	m	10^{+3}	kilo	k
10^{-6}	micro	μ	10^{+6}	mega	M
10^{-9}	nano	n	10^{+9}	giga	G
10^{-12}	pico	p	10^{+12}	tera	T

MULTIPLES AND SUBMULTIPLES

2. The distinction between energy and power

It is essential to avoid the common confusion between energy and power. Let us take the case of work, involving mechanical energy: work is done every time a force is applied to displace a body over a given distance; power is the rate at which that work is done, i.e. it gives the supply of energy in unit time. Energy 'can do' a number of things; power measures the velocity with which these things can be done. Power accordingly involves energy and time: in order to function, every appliance, every system needs an energy output. Depending on circumstances, we speak of the power of the appliance or of the power of the source supplying that instrument. In the last century, physicists often used the term horse-power (hp) as a unit of power; it is the power of a steam engine capable of doing the work of one horse. Today, the international unit of power is the watt (W) which corresponds to an output of one joule per second. Thus a motor with a power rating of one kilowatt supplies 60 kJ of mechanical energy a minute, and a 100 W light bulb uses up 0.1 kWh of energy every hour.

Unit	Abbr.	Example
Watt (joule/second)	W	Bicycle lamp
Horse power	hp = 736 W	Ten times the power of a man
Kilowatt	kW	Pair of horses in harness
Megawatt	MW	Motor of a racing car
Gigawatt	GW	Nuclear reactor

ORDER OF MAGNITUDE OF VARIOUS UNITS OF POWER

CHAPTER II: THE PRINCIPLES OF THERMODYNAMICS

I. THE FIRST LAW OF THERMODYNAMICS

1. The energy of an isolated system is always conserved

Let us take 'a piece of the universe' (a gas enclosed in a vessel, a machine, ...) that exchanges nothing (neither matter nor energy) with the environment. In the jargon of physicists, that system is said to be isolated. The total quantity of energy present in that system - its internal energy U as physicists call it - does not change. If Δ is used to refer to changes in magnitude, then:

$$\boxed{\Delta U = 0 \text{ in an isolated system}}$$

In other words

> the internal energy of an isolated system is constant

That does not mean that nothing happens in the system: work can be transformed into heat and vice versa. But when the internal energy U remains constant, the heat produced must be equal to the work done. For that reason the first law of thermodynamics is also known as the principle of equivalence; as we said earlier, all forms of energy can be converted into one another.

2. Exchanges of energy

In reality, few systems are isolated. Most exchange energy with their environment; the internal energy of such systems increases or diminishes depending on whether the sum of the energies it receives is greater or smaller than the sum of the energies it surrenders. We can express this fact by the following equation:

$$U_f - U_i = \Delta U = Q + W$$

when

U_i is the initial internal energy of the system

U_f is the final internal energy of the system

Q is the heat exchanged

W is the work done.

If we compare two successive states of a system, for example of a machine, taking into account its exchanges with the environment, we find that the energy of the whole (system + exterior) has not changed. In effect, if the system has surrendered a given amount of energy, that energy, which can neither be created nor destroyed, is necessarily found back in the environment. There can never be any energy losses(1). Conversely, if the system has

(1) The term 'energy loss' as used by engineers and economists refers to transformations of energy into forms that have ceased to be economically viable.

absorbed energy, that energy must have come from the environment. The principle of equivalence of heat and work extended to all forms of energy, is the principle of the conservation of energy, which can be expressed most generally as:

Energy can be transformed but is conserved

3. Concepts of calorimetry

We know various sources of heat (wood, electric currents, etc.) and we know how to measure the quantities of heat exchanged directly or indirectly. When heat is surrendered to a homogeneous body(1), the temperature will either increase or it will remain constant during the change of state.

In the first case, the body remains in the same phase (solid, liquid or gas). The thermal capacity of a body is the quantity of heat (ΔQ) required to raise its temperature by ΔT.

$$C = \frac{\Delta Q}{\Delta T}$$

In standard calculations, the water equivalent is often used instead:

$$C_{water} = 1 \text{ calorie/gram/degree}$$

The quantity of heat ΔQ needed to raise the temperature ΔT of a body by T is therefore given by

$$Q = C \Delta T$$

When changes of state are involved, the addition of heat to a homogeneous body does not produce a rise in temperature. This is notably the case when boiling water turns into steam but stays at a temperature of 100°C (or 373°K). The energy needed to obtain that change of state is called latent heat. We distinguish three types of latent heat:

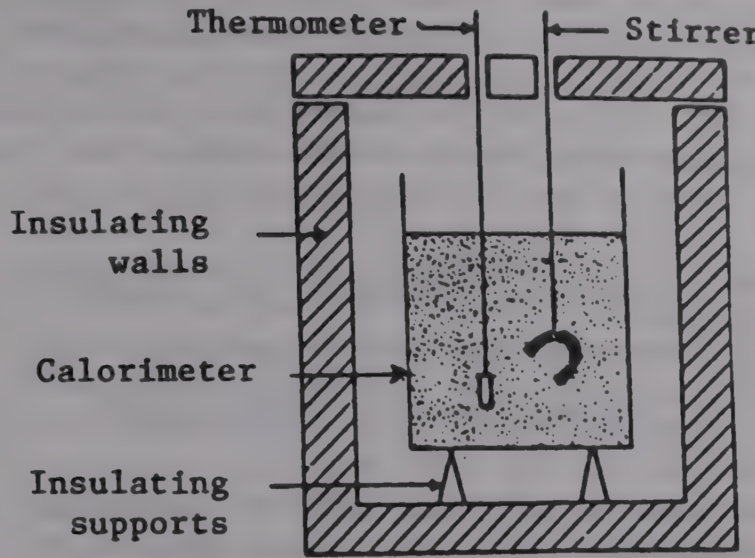
the latent heat of fusion L_f associated with the change of a solid into a liquid;

the latent heat of vaporization L_v associated with the change of a liquid into vapour;

the latent heat of sublimation L_s associated with the change of a solid into a vapour.

These latent heats are determined experimentally. They are usually expressed in kilocalories per gram (or per mole). Latent heats and thermal capacities are generally found with the help of a calorimeter (see diagram below). By and large, a calorimeter consists of a vessel filled with water. It usually contains a thermometer and a stirrer (to hasten thermal equilibrium), the whole being placed into an insulating jacket to avoid thermal exchanges with the environment.

(1) It is more convenient to consider homogeneous bodies (iron, water, oxygen) than mixtures (solutions, alloys) which have more complex properties.



SKETCH OF A CALORIMETER

In practice, the body whose capacity we wish to establish, is plunged into the calorimeter and the lid closed. The quantity of heat surrendered by the body to the water is deduced from the change in temperature of the water in the calorimeter.

It should be noted that, in general, some heat is also surrendered to the calorimeter itself and to its accessories (wall of vessel, thermometer). We refer as the water equivalent m_w of the calorimeter to the mass of water having the same thermal capacity as the calorimeter and its accessories under experimental conditions. Example:

A calorimeter contains two litres (2 kg of water at 20°C. We add 0.5 litres of water at 40°C. The temperature settles down at 23.8°C. We now wish to calculate the water equivalent of the calorimeter.

$$(2000 + m_w)\ (23.8 - 20) = 500\ (40 - 23.8)$$

Heat received by the calorimeter = Heat surrendered by the hot water

whence m_w = 132 g

4. Chemical transformations

In the eighteenth century, Lavoisier anticipated the principle of the conservation of energy with his famous: 'Nothing can be lost, nothing created'. But he reserved it for the conservation of matter in chemical reactions. It was shown later that the same principle also applies to energy. How precisely can it be applied to chemical reactions?

Let us take one of the most common of these, the combustion of sugar, which can be represented as:

$$\text{glucose + oxygen} \longrightarrow \text{carbonic gas + water + heat}$$

or using chemical symbols:

$$\underset{\text{(initial state)}}{C_6H_{12}O_6} \longrightarrow \underset{\text{(final state)}}{6\ CO_2 + 6\ H_2O + \Delta H}$$

ΔH represents a release of heat (final state) (exothermic reaction). ΔH, which is called the enthalpy(1) of the reaction, corresponds to the difference in energy level between the final state and the initial state of the system. In the case under review, the reaction is exothermic, the system surrenders energy to the outside, whence $\Delta H < 0$. In other words, the variation in enthalpy corresponds to a loss of heat by the chemical system:

Scale	$\wedge$ - -	- E_i (initial energy of the system)
of	ΔH	ΔH = enthalpy of the reaction = $E_f - E_i < 0$
energies	$\vee$ - -	- E_f (final energy of the system)

The value of the enthalpies of all the chemical reactions, and especially of the combustion, is of particular interest to us, because it is independent of the path taken by the system when changing from the initial to the final state.

In the case of the combustion of a gram of glucose, ΔH is about - 4 kcal.

Enthalphy should be correlated with the energy value of various substances, especially that of fuels and foodstuffs.

II. THE SECOND LAW OF THERMODYNAMICS

1. The energy of an isolated system must become degraded

The second law of thermodynamics is based on a number of established phenomena, including:

(a) The profound difference between 'heat energy' and 'work energy'

Stretching a spring ($W > 0$) is by no means the same as heating it ($Q > 0$) even though the same amount of energy ($W = Q$) may have been supplied in both cases, and even though the internal energy may have been increased by the same amount:

$$\Delta U = W = Q > 0$$

(b) The difference in quality between heat produced by sources at different temperatures

Counting calories is not enough, we must also evaluate their relative importance. Thus a source of warm water (for instance the Gulf Stream) can supply vast numbers of calories to bodies at a lower temperature, but all these calories would be insufficient to boil an egg, a feat that can be performed with a much smaller number of calories at a much higher temperature.

(c) The irreversibility of certain operations

Let us take the case of a litre of water at 99°C and a litre of water at 1°C (initial state); let us mix them: we obtain two litres of water at 50°C (final state). It is evident that $U_f = U_i$. And yet, it is not possible to restore the initial state, especially of the water at 99°C, without an additional input of energy.

(1) For transformations at atmospheric pressure, it is often more convenient to use enthalpy than internal energy.

The above examples, apparently quite unrelated, can be explained with the help of one and the same law:

The energy of an isolated system undergoing transformations becomes degraded

This assertion calls for an explanation. Its most important implication is that though it is possible to transform all other forms of energy into thermal energy, the opposite transformation, that of thermal energy into other forms of energy, can never be total: part of the initial energy always remains in the form of low temperature heat. This effect is known as degradation of energy. We can sum it up with the help of the following diagram which shows what happens to x calories during transformations of energy (R which is always smaller than 1, is the efficiency of the transformation process).

Energy other than heat x calories	$\longrightarrow$	Heat x calories
Energy other than heat x R calories Residual heat x (1 - R) calories	$\longleftarrow$	Heat x calories

2. The efficiency of machines

When we transform energy for a particular purpose, the amount of useful energy is always smaller than the theoretical amount available at the start. The ratio of the useful energy to the initial energy, the efficiency of the transformation, is always lower than 1. Carnot has shown that with heat engines, i.e. with machines that transform heat into work - and this is a consequence of the second law of thermodynamics - the partial transformation of a quantity of heat Q into mechanical energy must necessarily proceed from a 'hot source' at a temperature T_h to a 'cold source' at a temperature $T_c < T_h$; he has also shown that the heat transformed into work W cannot exceed W_{max}:

$$W_{max} = Q\,(1 - \frac{T_c}{T_h}),$$

where the temperature is expressed on the absolute scale, i.e. by adding 273°C to the normal centigrade (Celsius) scale. The ratio:

$$R_{max} = \frac{W_{max}}{Q}$$

is still called the Carnot efficiency of the engine.

It must be stressed that this efficiency is an ideal which cannot be attained in practice. Real engines always give rise to friction, and to escapes of heat.

3. Free energy and entrophy

On the basis of the internal energy of the system, we can define the maximum fraction of that energy which can be converted into 'noble' (non-thermal) or available energy ('free' energy):

Internal energy = free energy + degraded energy

or:

$$U = F + Q_r,$$

where U = internal energy

F = free energy

Q_r = degraded energy

The maximum efficiency R_{max} of a transformation is defined as:

$$R_{max} = \frac{F}{U} = \frac{U - Q_r}{U} = 1 - \frac{Q_r}{U}$$

or

$$R_{max} = 1 - \frac{\text{degraded energy}}{\text{internal energy}}.$$

In the case of chemical reactions - for instance the combustion of sugar - the system experiences a change in internal energy ΔU such that

$$\Delta U = \Delta F + \Delta Q_r.$$

The change in free energy can therefore be written as

$$\Delta F = \Delta U - \Delta Q_r$$

ΔQ_r can be expressed as the product of two terms, namely the temperature T and ΔS, the change in entropy:

$$\Delta Q_r = T \times \Delta S$$

Degraded energy = Temperature x change in entropy.

Free energy is therefore the difference between the total energy and the product T x ΔS, which allows us to consider entropy as a measure of the inevitable 'losses' associated with a transformation at a temperature T. For these losses to be zero (and the maximum efficiency to be 1), there must be a zero variation in entropy ($\Delta S = 0$), or an absolute temperature T = zero, which is impossible.

The greater the entropy S, the smaller the fraction ΔF of ΔU that can be transformed into noble energy: this explains why the entropy of a system is a measure of the degradation of the energy of that system(1).

The unit of entropy usually used is the clausius (calorie per absolute degree). The joule per absolute degree is also used.

4. Entropy and the irreversible degradation of energy

In an isolated system, energy can neither be created nor destroyed. Let us take the case of an oil field. The extraction of petroleum evidently goes hand in hand with a decrease in the internal energy of the oil field; but by virtue of the first law of thermodynamics, all the initial energy is found back in other forms (movement of vehicles, electricity, heat, etc.): it is not destroyed, which would be flying in the face of the first law, but dispersed into the largest system we can imagine, namely the universe, which by definition 'has no exterior'.

If, by contrast, we study a system that opposes degradation (a green plant, a living being in the growing phase, etc.), we shall find that it is bound to be a subsystem dependent on a larger, isolated system that inevitably suffers a degradation of its internal energy (growing entropy): this is the counterpart of the decrease in entropy of the privileged subsystem.

If we take the case of our planet, the earth, a miniscule space-ship, life on it before the industrial revolution depended on the slow degradation of the star from which it draws its low entropy energy: the sun. Since the industrial revolution by contrast, human societies have been drawing on the earth's own reserves (coil, oil), which the irreversible degradation of the earth's resources.

5. Two interpretations of entropy

The definition of entropy we have given is useful for treating problems in thermodynamics. However, we can also define entropy as the measure, on our (macroscopic) scale of the relative disorder of matter on the molecular (microscopic) scale.

Take the case of water in its various states: in the frozen state, the molecules are distributed regularly in a crystal.

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(1) All the variables used in this section apply to the analysis of thermodynamic phenomena in an enclosure, that is, at constant volume. But in nature, notably on the surface of the earth, the processes involved generally take place at constant (atmospheric) pressure. The most appropriate variables in that case are enthalpy H and free enthalpy G:

$$H = G + Q_r$$

$$\Delta G = H - T \Delta S \qquad \text{with } H = U + pV,$$

where p and V are the pressure and volume of the system.

Standard tables give the enthalpy of all the classic chemical reactions. For a given system and a given temperature, the values of H and U, and therefore F and G are often very close to one another and for practical purposes the differences can often be ignored.

Practically immobile at very low temperatures, they oscillate more and more rapidly about their mean position as the temperature increases. Once the temperature rises above zero, the energy of vibration becomes large enough to break the crystalline bonds: we have fusion accompanied by a sudden increase in entropy. A new leap in entropy occurs with the vaporization of water at about 100°C.

There is yet another interpretation of entropy. Suppose we have a box separated by a partition into two compartments of equal volume and at the same temperature.

On the one side of the wall we have a gas A ('red' molecules), on the other side a gas B ('white' molecules). When we withdraw the partition and wait for a few minutes, we shall be left with a mixture with the same energy and same temperature as the initial whole. We have proceeded from situation 1, with separate 'red' and 'white' molecules to a situation 2 in which the molecules are completely mixed up.

We also know that, had we started with situation 2, the molecules would never develop towards situation 1, without external intervention, that is, without an input of energy.

The last example shows that the concept of entropy involves not only <u>disorder</u> but also <u>irreversibility</u>: the change from 1 to 2, which is accompanied by an increase in entropy, is irreversible.

III. MASS AND ENERGY

1. The conservation of mass

The discovery of the law of the conservation of matter was one of the greatest discoveries of science. Though foreshadowed in antiquity, this law was not established empirically until the end of the eighteenth century. In 1789, the father of modern chemistry, Antoine Laurent Lavoisier, wrote: 'We must take it as an incontestable axion that in all the natural elements nothing is created; an equal quantity of matter exists before and after any experiment (...) and all that is produced are changes in the combination of the elements involved'.

This principle, which is basic to any understanding of the physical world and of the mechanics of chemical reactions is known as the principle of the conservation of mass. Yet despite its importance, it is not fully correct.

2. Einstein's contribution

More than a century after Lavoisier's discovery, Albert Einstein raised serious doubts about the universal validity of this principle.

Einstein showed that the mass of a particle varies as the velocity with which that particle moves relative to the observer. Thus the mass of a particle travelling with a velocity relative to an observer becomes:

$$m = \frac{m_o}{\sqrt{1 - \frac{v^2}{c^2}}}$$

where m_o is the mass of the particle at rest relative to the observer and c the velocity of light in a vacuum (300,000 km/s), a limiting velocity that no material particle can exceed. In the case of the relatively small velocities normally recorded on earth, moving mass can, to all intents and purposes, be equated with rest mass. Even in the case of an aeroplane moving with the velocity of sound (or 0.3 km/s), the ratio $\frac{v}{c}$ is of the order of

$\frac{1}{1000,000}$ and hence $\frac{v^2}{c^2}$ is of the order of $\frac{1}{1000,000,000,000}$ so that m barely

differs from m_o. However, Einstein's revolutionary ideas had other consequences, among them the equivalence of mass and energy.

3. The equivalence of mass and energy

The increase in kinetic energy ΔE_c of a particle of mass m_o which changes from rest to velocity v is given by

$$\Delta E_c = \frac{1}{2} m_o v^2$$

on condition, as we know today, that that velocity is relatively small in comparison with the velocity of light. Otherwise, following Einstein, we must also consider a change in mass and define the kinetic energy E_{cr} in a different way, namely by the equation:

$$E_{cr} = (m - m_o) c^2$$

or:

$$E_{cr} = m_o c^2 \left(\frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} - 1 \right)$$

When $\frac{v}{c} < < 1$, we can write:

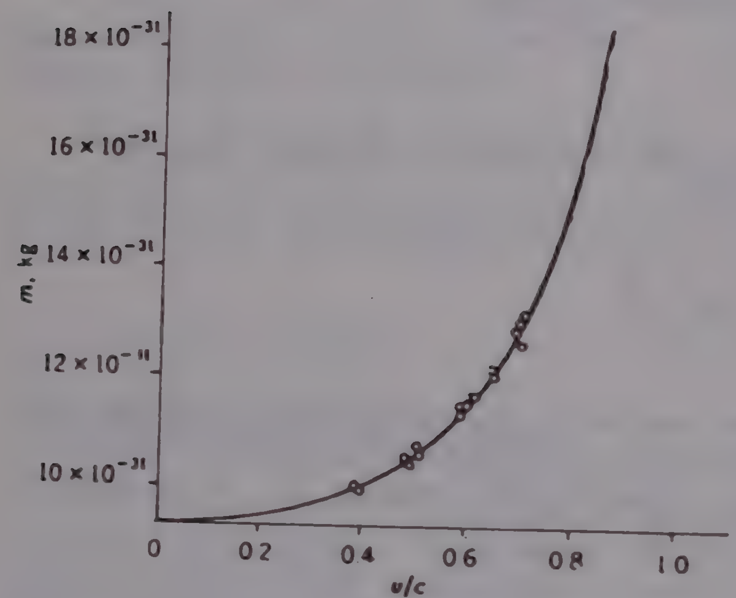
$$\frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \simeq 1 + \frac{1}{2} \cdot \frac{v^2}{c^2}$$

which takes us back to the classic expression of kinetic energy:

$$E_{c\,cl.} = \frac{1}{2} m_o c^2 . \frac{v^2}{c^2} = \frac{1}{2} m_o v^2$$

Kinetic energy is nowadays defined as the product of c^2 and the increase in mass introduced by the motion; we are back with the fundamental idea of the equivalence of mass and energy, which can be generalized in such a way as to embrace other than kinetic forms of energy. We can then state the following principle:

> Whenever an amount of energy E is bestowed upon a material object its mass m is increased by $\Delta m = \frac{E}{c^2}$



The graph shows how the mass of an electron varies with its velocity relative to an observer. The graph represents the equation $m = m_o (1 - v^2/c^2)^{-\frac{1}{2}}$, while the circles show the experimental results obtained by Bucherer and Newmann in 1914. The curve tends to infinity as $v \longrightarrow c$.

We can also put it in more classic form:

$$E = \Delta m \, . \, c^2$$

That equation signifies that an object at rest has a rest energy of $E_o = m_o c^2$.

We can now generalize the principle of the conservation of energy. <u>For an isolated system of rest mass m_o</u>,

$$\boxed{m_o \, . \, c^2 + U = \text{const.}}$$

where $m_o c^2$ is the total rest energy of the system and U its internal energy as defined above.

4. <u>Nuclear fission and fusion</u>

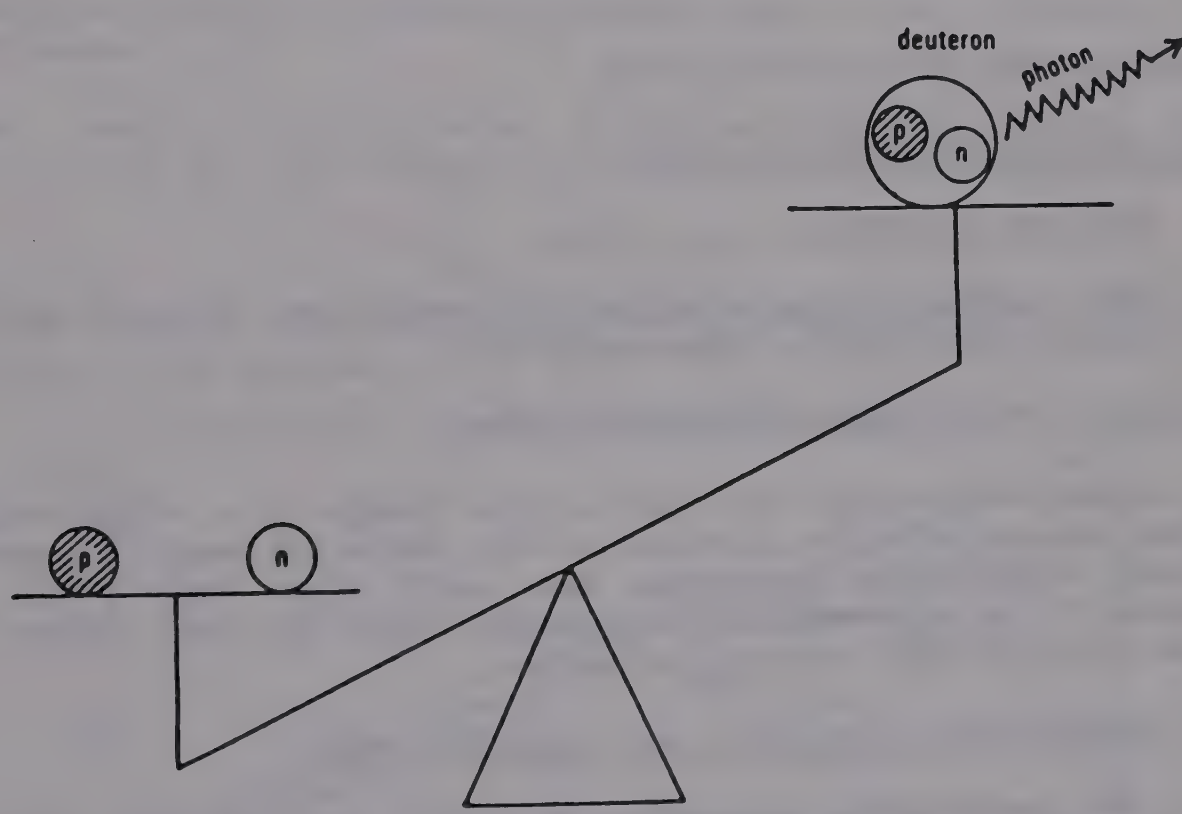
Mass, according to Einstein, is the equivalent of energy in all its manifestations. Thus energy and matter are two aspects of the universe. The changes in mass accompanying the changes in energy of a system are minute. Even so, the idea of transforming mass directly into useful energy seemed appealing, for it held a promise of fabulous quantities of energy.

That promise has now been fulfilled: when a fragment of uranium is bombarded with heavy neutrons, it is broken down into lighter elements, the sum of whose masses is smaller than the initial mass of the uranium. Einstein's theory was confirmed for better or for worse: for worse, because the first atomic bomb was dropped a few years later; for better, because the process of nuclear fission can be controlled and confined in a reactor and the energy can be recovered in the form of heat and used to produce electricity.

A simple comparison shows the importance of the leap forward in the concentration of energy produced through the control of nuclear energy: while a 600 MW thermal power station burns up several trainfuls of coal a day, a 600 MW nuclear power station needs about one ton of uranium to run for a whole year.

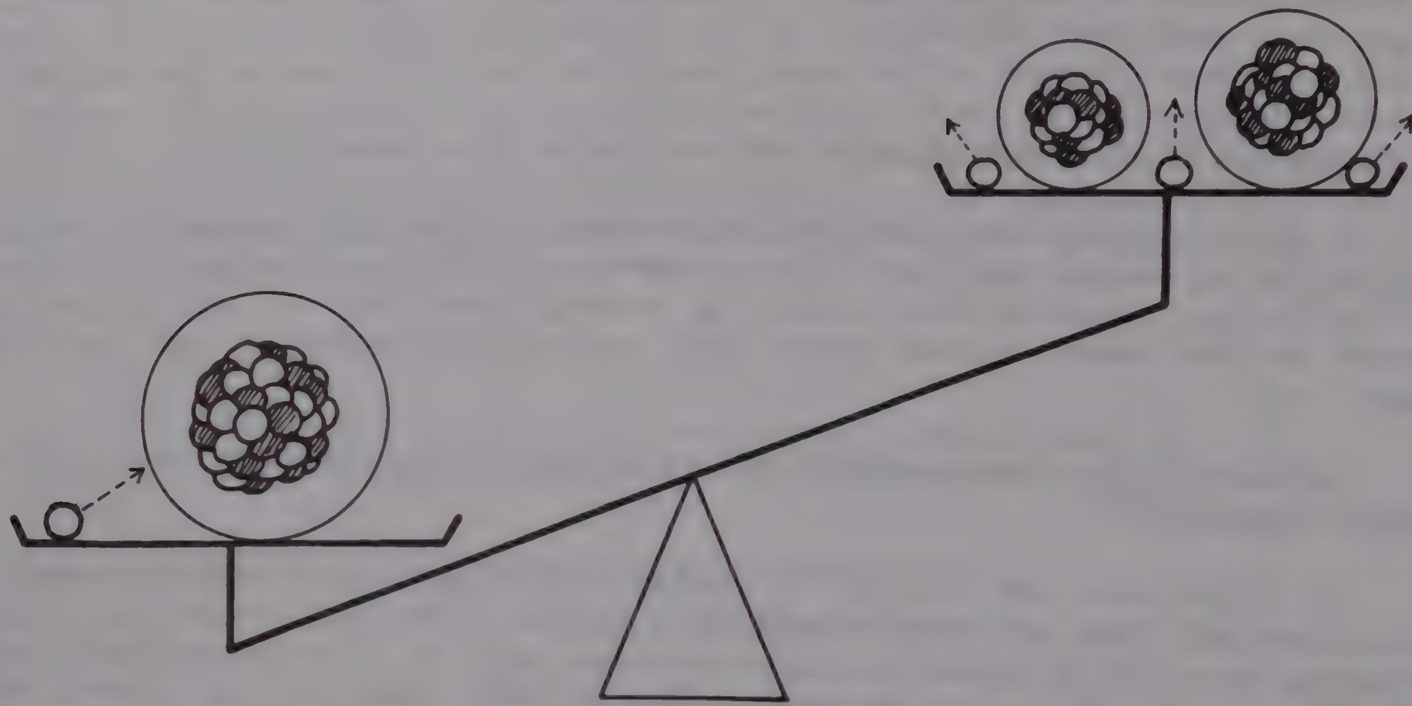
Nuclear fusion (see section V), by contrast, is based on the union of nuclear particles.

To illustrate the release of energy resulting from a rearrangement of atomic nuclei, the astrophysicist Hubert Reeves (1981) has drawn the following diagram, in which a separate proton-neutron pair is balanced against a pair united in one nucleus, the deuteron. That balance does not, of course, exist, but physicists have developed instruments that enable them to make indirect measurements of the mass of various particles, the elementary components of matter.



A nuclear bond. A separate proton and the neutron are heavier than a proton and neutron combined in a single system (the deuteron). The difference in mass is liberated in the form of energy (a gamma ray) at the moment of their combination. This difference in mass, close to one thousandth, is characteristic of nuclear forces.

We can imagine a similar diagram to illustrate the case of nuclear fission:



During fission, the uranium nucleus (left) captures a neutron and breaks it into two parts (right), with a consequent expulsion of neutrons and the release of energy (200 million electron-volts).

IV. ENERGY CONTENT AND CALORIFIC VALUE

1. Fuels and the production of heat

(a) Fuel and combustion

The oldest method of producing heat is combustion. It is an exothermic chemical reaction which can be represented by:

fuel + oxidant ⟶ reaction products + heat.

For combustion to occur the fuel must be brought to a sufficiently high temperature, generally in the presence of air. Fuels are usually classified by their origin: fossil fuels (petroleum, gas, coal), plant fuels (wood, straw), etc. However, it is more sensible to classify fuels by their energy-giving properties, which we shall now try to define.

(b) Energy-giving properties and calorific value

Among the energy-giving properties of a fuel, its calorific value is the most important. It is normally defined as the number of heat units released by the complete combustion of a kilogram of fuel, in the case of solids and liquids, and of a cubic metre of fuel in the case of gases. These values are determined by placing the fuel to be tested in a closed calorimeter and supplying it with oxygen. Combustion is usually started with the help of a resistance; the rise in the temperature inside the calorimeter when combustion is completed and thermal equilibrium re-established enables us to calculate the heat released by the combustion of the sample.

The calorific value thus obtained, measured at constant volume, is called

$$\boxed{C_{cv} = \text{calorific value at constant volume}}$$

In most heating devices (boilers, stoves) combustion takes place, not at constant volume, but at constant, usually near-atmospheric, pressure. We must accordingly make a correction which enables us to change C_{cv} into:

$$\boxed{C_{cp} = \text{calorific value at constant pressure}}$$

Heating engineers use yet another expression, namely, net calorific value. How is it defined?

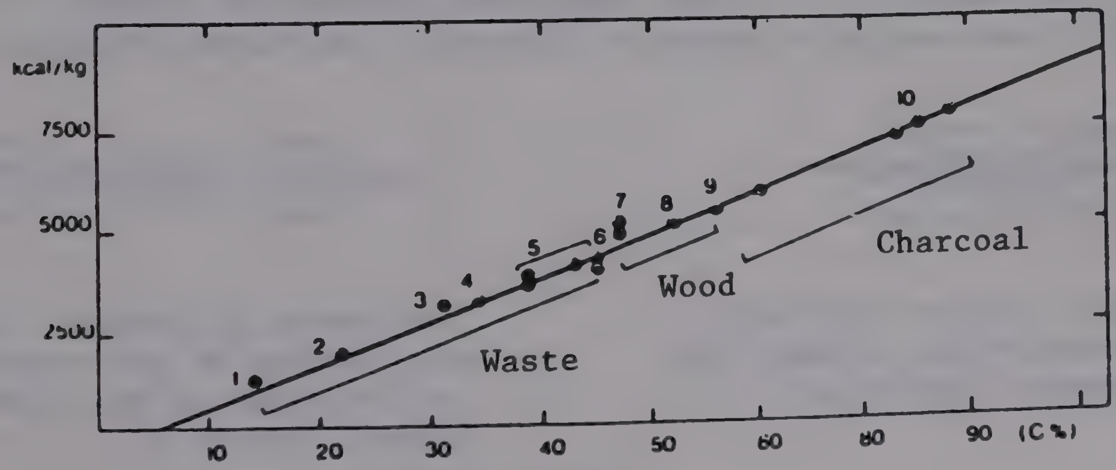
When combustion takes place in a calorimeter, the combustion products remain inside. Consequently we measure all the heat liberated by combustion. In particular, the energy spent on evaporating the water contained in the sample or formed during combustion is recovered when the water recondenses. The resulting calorific value is known as the gross value, and is greater than the value obtaining in heating installations. We refer to that value as the net value. It is the heat produced on combustion of the fuel at any given temperature with the fuel products cooled to the initial temperature, the water vapour remaining uncondensed.

In practice, heating engineers invariably use the net calorific value at constant pressure.

We can classify calorific values of various substances by their carbon (C) content, expressed as a percentage in accordance with the empirical equation

$$C_{cc} \simeq 100\ C - 400$$

From the diagram below, we can read off the calorific value of various fuels produced by the biomass.



1 : Sewage
2 : Manure
3 : Papermill sludge
4 : Urban refuse
5 : Agricultural residues
6 : Sawdust
7 : Bagasse
8 : Wood
9 : Bark
10 : Charcoal

CORRELATION BETWEEN CALORIFIC VALUE AND CARBON CONTENT

2. Food

Food supplies us with the energy needed:

(1) for all the cellular phenomena and automatic movements indispensable to our survival;

(2) for our, essentially physical, activities which use up relatively large amounts of energy.

We can use the simile of 'slow combustion' to describe the digestion of food by our organism, with a consequent liberation of energy. The energy content of the foods men and animals eat is partly preserved in their excreta (it should be remembered that cow dung, in particular, makes good fuel) and for the rest dissipated in the form of low temperature heat.

To determine the calorific value of a food, we must know its

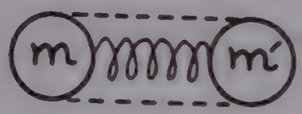
(1) water content (which has no energy value);

(2) its relative carbohydrate content (sugars and starches, mainly found in cereals); its relative protein content (nitrogenouss matter mainly found in meat and fish) and its relative fat content (mainly found in fats and oils).

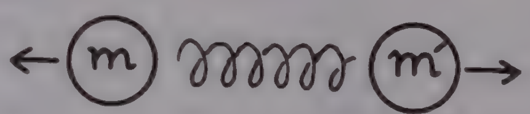
Knowing that 1 g of carbohydrate or 1 g of protein supplies an organism with 4 kcal and that 1 g of fat gives 9 kcal, we can determine the calorific value of a given quantity of a given food (1 calorie = 4.18 joules).

3. Representations of potential chemical energy

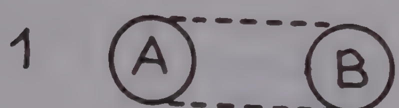
For educational purposes, it is often convenient to use a diagrammatic representation of the energy content, the bond energy and the potential chemical energy of a substance - different expressions of one and the same reality. Thus we can depict the potential chemical energy of the link between two atoms as the energy of a spring compressed between two masses. If the link is broken, the bond energy is suddenly liberated (exothermic reaction).



The two masses m and m' are held in a sheath that helps to keep the spring compressed (potential energy E_p)



The sheath is broken. The potential energy of the chemical bond is liberated in the form of kinetic energy E_c.



The two atoms A and B are linked together in the molecule AB by the potential chemical energy of the bond E_p

The bond is broken. On the microscopic scale, the bond energy is transformed into kinetic energy, which takes the form of heat on the macroscopic scale.

This over-simplified representation will probably be ridiculed by physicists, but it does bring out the fundamental importance of the potential chemical energy of fuels and foods, in our activities no less than in our biological survival.

APPENDIX II

DATA FOR DRAWING UP ENERGY BALANCES

Eco-energy analysis (EEA) can be treated as a didactic exercise and applied to a farm or a village ('urban' ecosystem on a reduced scale). Pupils in the final stages of their secondary education can easily participate in this type of activity, and have, in fact, done so already(1).

The main procedures and essential technical information are set out below.

(1) Delimitation of the system

There must first be a spatial delimitation of the unit studied: depending on the case, the limit can be geographic (e.g. a valley, a farm, ...) or administrative (e.g. a co-operative, district, a county, ...). The system is also defined by its relations with the outside. We must therefore determine which of these will have to be taken into account.

(2) The collection of data

The 'spatial' data of the system under review will be based on:

national (energy and agricultural) statistics;

balance sheets published by local bodies (co-operatives, farms);

questionnaires.

The material data (e.g. tonnages of harvests, weight of motorized units, amounts of fertilizer, quantities of fuel, ...) will be collected first, followed by spatial and temporal data (e.g. area under cultivation, hours needed to work it, ...).

Purely financial accounting methods are of little help since they often mask the fundamental problems revealed by material and energy balances. However, they are sometimes used in EEA to examine management procedures. To surmount certain technical difficulties of EEA, it is also possible to make use of money-energy transformation coefficient; the most common of these is the GNP/total energy consumption ratio of a country.

(3) Processing the data

The raw data must be processed in such a way as to yield magnitudes that can be transformed into energy units. To that end, we introduce various energy values, energy costs, transformation coefficients, ... In practice, we adopt the following figures:

Human labour

Developed countries: farmer considered as a simple producer (his own consumption is not taken into account):

100 kcal/h for light work

200 kcal/h for medium work

300 kcal/h for heavy work

(1) Assistance can be obtained from the EDEN group. Write to: Christine SOUCHON, Treasurer, EDEN Group, 18 rue des Fosses St. Jacques, 75005 Paris.

Agricultural country with little or no mechanization; home-consumption; take the entire calorie count (of the order of 2,000 to 3,000 kcal/day, including that of non-working days which can be lower.

Draught animals: calorie count

Of the order of 40,000 kcal/day, including non-working days, for large animals.

Fuel: the following approximate figures can be used:

Petrol, fuel oil, lubricants:	10,000 kcal/l
Coal:	7,500 kcal/kg
Wood:	4,500 kcal/kg of dry matter.

The figure given for petroleum products is based on the specific energy demand which reflects the calorie count as well as the energy cost of obtaining the material(1), the other figures are based purely on the calorific value. For wood dried in air with a 20 per cent water content, the calorific value is of the order of 2,000 kcal/m^3, or 4,000 kcal/kg (value also applicable to peat and to cow dung).

Machinery

For the construction of agricultural machinery, we can use the computations of Berry and Fels (in Pimental *et al*. 1973) for motor cars, transposable for tractors and possibly for stationary machinery; we can put it that approximately two tonnes of oil equivalent are needed to produce one tonne of agricultural machinery, or 20,000 kcal/kg.

The total energy costs must be spread over the year bearing in mind the amortization (generally over ten years).

The annual maintenance costs, 5 to 10 per cent of the total energy costs must be added; this percentage can be evaluated in monetary terms by considering the ratio of the annual expenditure on repairs to the purchasing price.

Various authors have also computed the energy cost of an hour of tractor use, including the direct energy expenditure

e.g.	50 hp tractor:	45,000 kcal/h
	65 hp tractor:	55,000 kcal/h
	90 hp tractor:	100,000 kcal/h.

Electricity

Always consider the primary energy; there is a ratio of secondary energy (supplied to the consumer) to primary energy (total energy used to produce the electricity), which depends on the structure of the national grid (role of different sources: fossil fuels, hydraulic power, nuclear power, ...).

(1) Note: A multiplication factor of approximately 1.10 enables us to convert the calorie count of refined petroleum products into the specific energy demand.

In the most unfavourable case - production of electricity from fuel oil alone -: 1 kWh of electricity which should be equivalent to 861 kcal absorbs three times more, namely 2,583 kcal.

Fertilizers and pesticides

We shall use the following approximate values established for the United Kingdom:

nitrates:	19,000 kcal/ per kilogram of N
phosphates:	3,500 kcal/ per kilogram of P
potassium:	2,500 kcal/ per kilogram of K
herbicides, pesticides:	25,000 kcal/ per kilogram

N.B. It is the weight of the fertilizing element (N, P, or K) that must be considered, not the weight of the fertilizer.

The values depend on the 'structure' of the process used to obtain the fertilizer in particular countries: type of industry and synthetic procedures in the case of nitrates; distance from the deposits in the case of phosphates and potassium, ...

Materials (see the tables below)

There are great differences in the values listed in various sources. This is because:

(1) specific energy demand calculations by unit weight or unit volume of a material are used on different criteria:

some take the indirect energy into account, while others do not;

some use purely monetary computations based on inter-industrial exchange tables;

(2) the processes used to manufacture one and the same product are not the same at all times: in general, there has been an increase in energy efficiency, sometimes offset by various forms of waste. Various manufacturing processes can coexist at any particular period;

(3) the 'structure' of the manufacturing process: size of factory, relative importance of transport of raw materials, ..., must also be taken into account.

Calorific value of end products

In the case of food for human beings, we can use the following dry-weight conversion:

4 kcal per gram of carbohydrate (starch, sugar)

4 kcal per gram of protein (usually animal products)

9 kcal per gram of fat (fats, oils).

These figures give the amount of energy supplied by these substances to the human organism (and not their calorific value which is measured in a bomb calorimeter).

Cereal grains which contain approximately 10 per cent water and are made up of carbohydrates (the major proportion) and proteins (gluten) yield:

0.9 x 4 x 1,000 = 3,600 kcal/kg artificially dried

Oil seeds make a much greater calorific contribution - from 5,500 to 6,000 kcal/kg because of their high fat content.

Green vegetables and fruits, on the contrary, have a large water content (sometimes up to 90 per cent)

0.1 x 4 x 1,000 = 400 kcal/kg fresh weight

In the case of feed, we can use the fodder unit: 1 FU is equivalent to the calorific contribution of 1 kg of barley, or approximately 4,000 kcal/kg dry weight or 3,600 kcal/kg artificially dried.

As far as animal products are concerned:

(a) in the case of meat, we obtain approximately one-half of the carcase weight. Meat is two-thirds water, and we need merely apply the protein and fat conversion figures to the remaining weight to obtain the correct values, bearing in mind the relative proportion of these two constituents;

(b) the respective values of milk products, eggs, ... are listed in Table D below.

The tables are taken from J.P. Mercier, Energie et agriculture, 1978, and give the coefficients used in various types of eco-energy analysis.

Energy unit: thousands of kcal

(A) TYPICAL AGRICULTURAL INPUTS

Items or service	Specification	Calorie coefficient used			
		American	British		French
			Slesser	Leach	
Nitrate fertilizers					
Liquid ammonia NH_3	kg N		14.00	14.93	
Urea	kg N		18.46	19.95	
Ammonium sulphate	kg N		16.50	19.57	
Ammonium nitrate	kg N		15.24	18.16	
Average fertilizers[(a)]	kg N	18.52	15.77	19.11	19.52
Phosphates, mean P	kg P	3.35	3.34	3.34	3.53
Potassium fertilizers, mean K	kg K	2.31	2.32	2.15	2.44
Chalk	kg			0.48	
Herbicides, pesticides	kg	24.25	30.58	23.89	26.11
Tractor (including amortization, repairs, etc.)	50 hp/h			45.08	
	65 hp/h			54.86	
	90 hp/h			99.70	
Hybrid maize seed[(b)]		7.94		2.17	
Irrigation	tonne of water	0.73		(pumped)	
Construction material:					
Metal	tonne				13,400
Masonry	tonne				800

(a) France = Pimental + transport

(b) In Leach, seed deducted from output

Energy unit: thousands of kcal

(B) FUEL AND ELECTRICITY

Items or service	Specification	Calorific coeffient used			
		American	British		French
			Slesser	Leach	
Coal	tonne	7 300	0	7 790	
Natural gas	m^3	9.20	9.34	9.68	
Petrol	1	9.5	10.20	9.49	8.23
Gas oil	1	9.5	11.09	10.35	9.59
Fuel oil	1	9.5	11.99	11.13	9.45
Electricity	k x h		3.34	3.44	2.41
Oils and lubricants				131.4/t	
Transport	t x km	70 x 10^3kcal/acre		10^3kcal/t x km	

(C) VARIOUS RAW MATERIALS

Items or service		Steinhardt	Carillon	Leach
Steel and cast iron	kg	19		
Copper, brass and alloys	kg	1.9		
Paper	kg	6.1		
Plastics	kg	1.4		
Iron, wire, etc.	kg		12.73	70.96 x 10^3 kcal/t
Industrial foodstuffs for animals	kg			2.29

(D) AGRICULTURAL PRODUCTS

Items		Carillon	Leach	Leach Proteins by unit weight (kg)	Pimentel
Plants					
Maize	kg	4	2.93		3.97
Barley	kg	4	2.60	0.068	
Wheat	kg	4	3.44	0.103	
Potato	kg	0.9	0.76	0.021	
Sugar beet	kg	0.64	0.67		
Fodder	MS	3.9	2.53		
Maize - green fodder	kg	0.9			
Dry pulses	kg	4			
Green pulses	kg	0.08			
Oleaginous plants	kg	5.5			
Animals					
Cows' milk	kg	0.6	0.65	0.035	
Beef	kg	1.8	2.43	0.13	
Eggs	unit	0.096	0.08	0.105/kg	
Poultry	kg	1.6	1.44	0.208	
Pork	kg	3.3			
Mutton	kg	1.8	3.06		

APPENDIX III

GLOSSARY OF SOME TERMS RELATED TO ENERGY(1)

(1) This list is not exhaustive. The reader is advised to refer to the text for additional information.

BARREL: Approximately 160 litres (or 42 US gallons); 1 tonne of crude oil is roughly equivalent to seven barrels. An output of one barrel per day is roughly equivalent to 50 tonnes a year.

BATTERY: A device for converting chemical into electrical energy.

BIOMASS: In ecology, the quantity of organic matter represented by living beings (generally the vegetation, or plant biomass, but the term is also used for the animal biomass) found in a given area. Expressed as mass (g, kg or t) of dry matter (DM) or in energy units (kilocalories) per unit area (m^2, ha). In everyday language the term biomass is used to refer to materials (wood, agricultural waste, animal waste, agro-alimentary waste) produced by living organisms and capable of yielding energy.

BTU: British thermal unit: 1 Btu = 252 calories (or 1,056 joules).

CALORIE: Quantity of heat needed to raise the temperature of 1 g of water from 14.5°C to 15.5°C. One calorie = 4.18 joules. In the past, people also used the large calorie or Calorie, equal to 1 kilocalorie.

CALORIFIC VALUE: The number of heat units obtained by the complete combustion of unit mass of fuel. In fuels containing hydrogen, which burns to water vapour, we distinguish between <u>gross</u> and <u>net</u> calorific values. The <u>gross</u> value is the total heat developed after the products are cooled to the starting point and the water vapour is condensed. The <u>net</u> value is the heat produced on combustion of the fuel at any temperature with the flue products cooled to the initial temperature, the water vapour remaining uncondensed.

COMBUSTION: Generally a very rapid combination of oxygen with combustible substances. Combustion an exothermic reaction, is generally used to produce heat, but it also produced light.

The chief combustible substances or fuels are various combinations of the two elements carbon and hydrogen; the most important characteristic of a fuel is the quantity of heat generated by unit mass or volume of that fuel.

ECOSPHERE: The set of all ecosystems; it is the layer on the earth's surface holding all living beings (biosphere) and all the elements constituting their living environment (biotopes).

ECOSYSTEM: 'Unit' or 'piece' of nature characterized by: (1) its structure: an ecosystem is a coherent and homogenous whole comprising a biocoenosis (the association of animals and plants together, each with a specific population) and a biotope (a set of physical and chemical elements supporting the biocoenosis and determining its living conditions; it is therefore also the entire set of ecological conditions); (2) its functioning: an ecosystem is traversed by an energy flow and involves cycles of such chemical elements as N, P, K, Ca, ...

ELECTRON-VOLT: Unit of energy used in nuclear physics: it is the kinetic energy acquired by an electron losing one volt of potential. One eV = 1.6×10^{-19} joules.

ENERGY: See the whole of this paper and especially the sections devoted to definition and forms.
- <u>Mechanical energy</u> comes in the form of <u>kinetic energy</u> (the energy of a body by virtue of its motion) or of <u>potential energy</u> (the energy of a

body by virtue of its elevated position) or of 'elastic' energy (the energy of a compressed spring).
- Chemical energy: the energy stored in chemical compounds (bond energy); it is liberated during so-called exergonic (generally exothermic) reactions, but absorbed during endergonic (generally enderthermic) reactions. We speak of potential chemical energy in the case of bodies capable of liberating energy by rapid combustion (wood, coal, petrol) or by slow combustion (food, ...).

ENERGY ANALYSIS: The evaluation of the flow of energy in natural or social systems, used especially to determine the energy cost of industrial processes. For eco-energy analysis (AEE) see page 24.

ENERGY EFFICIENCY: A term generally defined as the ratio R of the amount of usable energy supplied by a converter to the amount of energy it uses up. This ratio is always smaller than 1.

ENERGY REQUIREMENTS: Term used to refer to quantities of - mainly fossil - energy under the earth's surface. We must distinguish between established reserves and potential or ultimate reserves. It must be stressed that our knowledge of reserves depends on geological prospecting and that economically viable reserves are generally smaller than the established reserves. There is evidence to suggest that the reserves of fossil fuels - established or potential - are limited, and that they must therefore be used prudently.

ENERGY RESOURCES: The term 'resource' is generally applied to all parts of the environment needed by living organisms. Energy resources come in two categories: renewable resources mainly of solar origin (biomass, hydraulic resources, etc. ...) and non-renewable resources (fossil energy).

ENGINE: Generally a machine in which power is applied to do work; especially a machine for converting heat energy into mechanical work.

ENTHALPY: Function of state of a homogenous body, usually fluid, designated by H, such that $H = U + pV$, where U is the internal energy, p the pressure and V the volume. The variation in enthalpy of a system is equal to the heat received by the system during a reaction or a transformation at constant pressure (see Appendix I).

ENTROPY: Name given to the function of state (designated by S) characterizing the state of 'disorder' of a system. When a system at temperature T, undergoing a reversible change, takes a small quantity of heat ΔQ, its variation in entropy is given by:

$$\Delta S = \frac{\Delta Q}{T}$$

(see Appendix I).

FREE ENERGY: Function of state of a system in equilibrium, often expressed by F such that $F = U - TS$, where U is the internal energy, T the temperature and S the entropy of the system. If the system experiences a transformation at constant temperature, the variation in free energy of the system is equal to the work done on it (see Appendix I).

FRIGORIE: Term used by refrigeration industry; equals to one kilocalorie absorbed or 'removed' from a system.

GREENHOUSE EFFECT: The capture of solar energy by the atmosphere or by a glass or plastic surface. The greenhouse effect is due to the property of certain materials of being transparent to certain components of radiation (in the near infra-red region, for example), while being opaque to others (ultraviolet).

HEAT: Form of energy produced by the random movement of atoms or molecules in a body (see text, especially page 68 and Appendix I). The uses to which heat can be put depend largely on the temperature. We distinguish between low temperature heat (or low energy heat) below 100°C the applications of which are mainly confined to heating, and high temperature (or high energy, heat) which can be used in heat engines and is therefore capable of supplying mechanical energy.

HYDROGEN: The lightest element known, symbol H. The nucleus of the hydrogen atom consists of nothing but a proton. Hydrogen combines with oxygen to form water (H_2O). It is also present in petroleum products.

JOULE: Unit of energy equal to the work done when a force of 1 newton advances its point of application 1 m.

KILOWATT HOUR: (See watt hour). Unit of electrical energy: 1 kWh = 3.6 million joules.

OXIDATION: Addition of oxygen to another chemical element. Combustion is a special case of high temperature oxidation.

OXYGEN: Oxygen (symbol O) is an element indispensible for life on earth, and one that is moreover extremely plentiful, both on its own in molecular form (symbol O_2) in the terrestrial atmosphere (20 per cent) and also in combination with other elements, particularly with hydrogen to form water (H_2O).

PHOTOSYNTHESIS: Capture of solar energy by the chloroplasts of green plants, as a result of which water (H_2O) and carbonic gas (CO_2) in the atmosphere are converted into carbohydrates with a release of oxygen into the atmosphere. These photosynthetic reactions reflect the conversion of part of the solar radiation into energy stored in plants, with an efficiency that does not generally exceed just a few per cent.

PHOTOVOLTAIC CELL: Crystal semi-conductor generally made of silicon and used to convert ultraviolet solar radiation into electricity; its efficiency is very small - from 10 to 20 per cent.

POLLUTION: A term used to refer to any (undesirable) release of matter or energy into the environment, potentially damaging to plants, animals and human beings. The energy industries are responsible for many cases of water and air pollution. Thermal pollution is largely connected with thermal or nuclear electric power stations, which release the water used for cooling their boilers or reactors into rivers, lakes and seas.

PRODUCTIVITY: In ecology, the productivity of an ecosystem is the quantity of living matter it produces in unit time, generally a year. The quantity of matter that can be removed from an ecosystem without endangering its renewable character is a function of its productivity and not of its biomass.

POWER: The speed with which energy can be supplied or consumed by a system, or the rate of doing work. The unit of power is the watt.

QUAD: Abbreviation for quadrillion of Btu; 1 US quadrillion = 10^{15}. One quad is the equivalent of approximately 25 million tonnes of oil equivalent.

RADIATION: Generally used to refer to energy in electromagnetic form which travels in the vacuum with the velocity of light.

REACTOR: That part of the nuclear power station in which nuclear reactions take place to generate heat. The most commonly used type is the PWR (pressurized water reactor) which works with just enough pressure in the heat extraction circuit to prevent the water from boiling.

SYSTEM: In its most general sense, the word system refers to a coherent set of interacting physical elements that can be isolated from the rest of the universe with the help of appropriate criteria. The term covers a vast diversity of phenomena, ranging from such large structures as the solar system to such tiny systems as a preparation of micro-organisms for examination under a microscope. In the stricter sense, the word can be applied to such structures as the energy systems we have been examining. They are coherent sets of converters along the path of the energy flow from the resource to the final point of application (see ecosystem).

TCE: Energy released by the combustion of one tonne of coal (approximately seven million kcal).

TOE: Energy released by the combustion of one tonne of oil (approximately ten million kcal).

THERM: In the United Kingdom, a unit of heat equal to 100,000 British thermal units.

WATT (W): Unit of electric power equal to one joule/sec. It is more usual to use the kilowatt (kW).

WATT HOUR (Wh): Unit of electrical energy being the work done by one watt acting for one hour. One Wh = 3,600 joules; it is more usual to use the kilowatt hour (kWh).

APPENDIX IV

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ANRED - Agence Nationale pour la Récupération des Déchets, 2 square Lafayette, 49000 Angers, tel. (41) 88.98.25.

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EDF, Division de l'Information, 3 rue Messine, 75008 Paris, tel. 47.64.38.98. Regularly publishes an index of documentation on energy indicating many titles of works of various kinds available free of charge.

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(1) These are mainly agencies concerned with energy production and management and provide general documentation or information/publicity material free of charge. The ones shown here are French but similar bodies exist in most countries.